

**A SMALL OPEN ECONOMY MODEL WITH REMITTANCES:  
EVIDENCE FROM ARMENIAN ECONOMY**

**Ara Stepanyan<sup>#</sup>**  
**Anahit Tevosyan**

This project (No 07-050) was supported by  
the Economics Education and Research Consortium

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**Research area:** Macro, Financial Markets and Open Economy

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<sup>#</sup> This work was conducted when I worked at Research Department of Central Bank of Armenia.

**JEL classification:** E<sub>12</sub>, C<sub>51</sub>

**STEPANYAN A., TEVOSYAN A.: A small open economy model with remittances: evidence from Armenian economy. – EERC, 2008.**

This paper develops a small open economy model with remittances. The model features short-run nominal price rigidity generated by monopolistic competition and staggered re-optimization in output and import markets.

The model structure is closely related to similar models described in Svensson (2000), Gali and Monacelli (2002) and Monacelli (2005). This paper expands their model by introducing remittances. We find that this approach is closer to the Armenian economy because remittances have shaped main streams of economic developments during recent years.

This paper explores desirable monetary policy rules for a small open transition economy like Armenia, with high degree of dolarisation and huge remittances from abroad.

**Keywords:** remittances, nominal rigidity, incomplete pass-through, calibrations, simple rule

**Acknowledgements.** We would like to thank EERC experts, especially Diana Weinhold for valuable comments and suggestions that helped us to improve the paper.

**Ara Stepanyan**

Economist

IMF office of resident representative in Armenia

1 Melik Adamyan st. Yerevan, Armenia

Tel.: +37410 528960

Fax: +37410 545833

E-mail: [stepanyanar@yahoo.com](mailto:stepanyanar@yahoo.com)

**Anahit Tevosyan**

Senior Economist

Monetary Policy Department

Central bank of Armenia

Tel.: +37410 592894

E-mail: [atevossyan@yahoo.com](mailto:atevossyan@yahoo.com)

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## Non-Technical Summery

One of the enduring research issues in central banks is the transmission of monetary policy. How does monetary policy affect key economic variables like output, inflation and the exchange rate, by what magnitude, and with how long and variable lags? Estimated dynamic stochastic general equilibrium (DSGE) models with nominal rigidities have recently emerged as a quantitative monetary policy analysis and inflation-targeting tool.

In this paper, we develop a small open economy model with remittances, which features economic developments in Armenia and may serve for conducting and analyzing the monetary policy.

We introduce remittances in the model, because these huge financial inflows are one of the main determinants for economic developments in recent years, since:

- they constitute about 20 percent of GDP and have been growing more than 45 percent per year since 2002,
- the bulk of these remittances flow to the real estate sector and causes high growth in construction,
- these inflows have a significant effect on the exchange rate and have caused more than 40 percent appreciation in the national currency since 2003.

Impulse response and model in-sample simulation results show that introducing of real remittances gap brings value added to the model properties. While the standard shocks in the model create responses of main macroeconomic variables similar to the standard New Keynesian models, none of them are similar to the recent economic developments in Armenia. Only the shock to remittances is able to highlight the recent developments. In addition to this, the model in-sample simulation results suggest that introduction of real remittances gap improves the explanatory power of the aggregate demand equation. Based on the results of quantitative analysis the ERS rule is considered more desirable for Armenia, although the SIT rule ensures the lowest value of loss function. The analysis shows that the SIT rule generates higher volatility in the exchange rate, while ERS rule ensures less volatility of exchange rate and relatively low value of loss function. The further evaluation of ERS rule demonstrates that quite

aggressive response to inflation is needed for achieving minimum value of the loss function given to our model and the class of monetary policy rule.

According to the sensitivity analysis, the results presented in the paper are relatively robust.

## 1. Introduction

The Central Bank of Armenia (CBA) announced the move to implicit inflation targeting (IT) regime since January 1, 2006, with the intention of moving to a full-fledged inflation-targeting framework over the medium term. One of the preconditions for the successful adoption of inflation targeting is a well-designed macro model and a good understanding of the transmission mechanism. Estimated dynamic stochastic general equilibrium (DSGE) models with nominal rigidities have recently emerged as a quantitative monetary policy analysis and inflation-targeting tool.

In this paper, we develop a small open economy model with micro foundations, which features economic developments in Armenia and may serve for conducting and analyzing the monetary policy.

The model presented here is closely related to similar models described in Svensson (2000), Gali and Monacelli (2002) and Monacelli (2005).

First distinction from Svensson's model (2000) is that like Gali and Monacelli (2002) we derive potential output from supply block optimization conditions instead of using autoregressive flexible price output. This change has no influence on the final properties of the model, and it just makes the ways in which shocks (home and foreign productivity shocks) are transformed to the economy more proper and realistic. For example in Svensson's model, foreign output has no influence on flexible price output and only has an impact on aggregate demand. The derivations of flexible price output from supply block optimizations show that flexible price output is negatively related to foreign output. This type of derivation allows us to get more proper coefficients of influence of exogenous variables, which depend on micro parameters (elasticity of substitutions, degree of openness, etc). Due to the above-mentioned change, we have an equation for policy natural interest rate as an addition.

Second distinction from Svensson's model (2000) is the degree of exchange rate pass-through. We allow an incomplete exchange rate pass-through generated by monopolistic competition and staggered

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re-optimization in the import market as in Monacelli (2005). Because of the incomplete pass-through, our model obtains all features of Monacelli's model.

We then expand the model by introducing remittances in order to bring the model specification closer to the Armenian economy. These huge financial inflows are one of the main determinants for economic developments in recent years, since:

- they constitute about 20 percent of GDP and have been growing more than 45 percent per year since 2002,
- the bulk of these remittances flow to the real estate sector and causes high growth in construction,
- these inflows have a significant effect on the exchange rate and have caused more than 40 percent appreciation in the national currency since 2003.

In general, it is possible to introduce the remittances endogenously through the labor market, assuming that workers face the decision problem of whether to work abroad or in their home country. To do so, we would need assumptions about the labor market structure (free or monopolistic competition), presence of nominal wage rigidity, etc. The nature of labor market optimization introduces another inter-temporal link to the consumer optimization about the appropriate paths of consumption and wages, alongside the budget constraint. The mutual interactions of both decisions then get very complex and reduced form solutions cannot be found. In order to preserve clarity and intuition, it appears advantageous to introduce remittances exogenously into the aggregate demand and UIP equations. On the one hand, remittances growth shifts budget constraint and hence raises expenditure. On the other hand, remittances are denominated in foreign currency and are not dependent on interest rate differential. There is one remaining question related to incorporation of remittances: how to calibrate the coefficients of influence of remittances on output gap and exchange rate? We rely on the share of remittances in GDP, for calibration of the coefficient of remittances in aggregate demand. In case of UIP it is a little bit complex, we calibrate it based on import and saving propensities, trying to eliminate that part of remittances which either outflows from country through import or becoming foreign denominated assets (dollar denominated deposits or cash dollars under mattresses).

The model is calibrated for the Armenian economy. The derivation of main equations of the model from micro foundations allows us to derive model parameters from empirically plausible

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microeconomic parameters. We take into account the microeconomic parameters used in other developing and transition countries. The presented calibration of the deep structural parameters follows not only restrictions given by the micro-foundation, but takes note of basic stylized fact of the Armenian economy.

We do some exercises for revealing model properties and verification of model calibration. The dynamic impulse responses of temporary shocks show that the impulse response to the remittances shock generates a behavior of macroeconomic variables similar to the actual data that we had during the recent years.

For verification of model calibration, we did two types analysis. First, we estimated the structure shocks of the model (the difference between actual variables and model-produced variables given the actual in sample realization of exogenous variables). Second, we run simple VAR to ascertain whether model-produced impulse responses are consistent with those provided by the actual data.

In the model, the instrument of monetary policy is a short-term interest rate. For our analysis, we use a simple rule, which specifies the reaction of the interest rate as a function of a few macroeconomic variables. We do not rely on the optimal rule under commitment because of its complexity and lack of tractability.

Quantitative analysis is applied to assess the performance of various interest rate rules, which differ in their responses to inflation, output gap and exchange rate changes. Given these different results, we then explore a desirable interest rate rule for Armenia. After determining the type of interest rate rule, we estimate the numerical parameters of the rule minimizing the loss function, given our model structure and calibration.

Sensitivity analysis is used by varying the structural parameters of aggregate demand and supply for verification of robustness of the results.

The paper is organized as follows. Section 2 describes the relevant literature. Section 3 presents the small open economy model. Section 4 discusses the calibration of the model to stylized facts for Armenian economy and verification of model calibration. Section 5 includes the simulation results based on external and internal shocks and the assessment of performance of several interest rate rules. Section 6 discusses some sensitivity analysis. Section 7 presents the conclusions and policy recommendations. Appendices A-G contain some technical details.

## **2. Literature review**

One of the enduring research issues in central banks is the transmission of monetary policy. How does monetary policy affect key economic variables like output, inflation and the exchange rate, by what magnitude, and with how long and variable lags? As Lucas (1976) pointed out, traditional econometric models were unable to answer such questions, because their reduced-form parameters depended critically on the conduct of policy itself. As a result of Lucas critique, central banks have focused on structural macro-economic models to guide policy.

The existence of short run nominal price and wage rigidities generated by monopolistic competition and staggered price settings in output and labor markets permits a cyclical stabilization role for monetary policy, which is generally implemented through control of the nominal interest rate according to a monetary policy rule. The persistence of the effects of monetary policy shocks on output and inflation is often enhanced with other features such as habit persistence in consumption, adjustment costs in investment, and variable capital utilization. Early examples of closed economy DSGE models incorporating some of these features include those of Yun (1996), Goodfriend and King (1997), Rotemberg and Woodford (1995, 1997, 1998), and McCallum and Nelson (1999), while recent examples of closed economy DSGE models incorporating all of these features include those of Christiano, Eichenbaum and Evans (2005), Altig, Christiano, Eichenbaum and Linde (2005), and Smets and Wouters (2003, 2005).

Open economy DSGE models extend their closed economy counterparts to allow for international trade and financial linkages, implying that the monetary transmission mechanism features both interest rate and exchange rate channels. Existing open economy DSGE models differ primarily with respect to the degree of exchange rate pass through. Models in which exchange rate pass through is complete include those of Benigno and Benigno (2002), McCallum and Nelson (2000), Svensson (2000), Clarida, Gali and Gertler (2001, 2002), and Gertler, Gilchrist and Natalucci (2001), Gali and Monacelli (2004), while models in which exchange rate pass through is incomplete include those of Adolfson (2001), Betts and Devereux (2000), Kollman (2001), Corsetti and Pesenti (2002), Liu (2006), and Monacelli (2005).

In an empirical investigation of the degree of exchange rate pass through among developed economies, Campa and Goldberg (2002) find that short run exchange rate pass through is incomplete, while long run exchange rate pass through is complete. This empirical evidence rejects both local currency pricing



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and producer currency pricing. In response to this empirical evidence, Monacelli (2005) incorporates short run import price rigidities into an open economy DSGE model by allowing for monopolistic competition and staggered re-optimization in the import market.

The cores of New-Keynesian models are monopolistic competition and nominal rigidities. The basic model of monopolistic competition is drawn from Dixit and Stiglitz (1977). It's worth notice that imperfect competition alone does not lead to monetary nonneutrality. Price stickiness remains critical to generating real effects of money. The greatest research in this area is done by new Keynesian economists Ball, Mankiw, and Romer (1988). They study imperfectly competitive economies and show that the cost of nominal rigidities for price setters can be much smaller than the macroeconomic effects. There is a relatively little research done in this area for emerging and transition countries. Examples include Lyziak (2002) for Poland, Gavura, Reľovský (2005) for Slovak economy, Benes, Hlédik, Vávra and Vlcek (2003) for Czech Republic. The model's structure of these works is based on the description of the transmission mechanism for small open economies suggested by Laxton and Scott (2001). These are the gap models, which are based on the premise of the monetary cycle theory and defer from each other only by calibrated parameters.

The following analysis for emerging and transition countries more advanced and based on micro foundations.

Choudhri (2005) uses stochastic dynamic general equilibrium model to compare and evaluate the performance of alternative interest rate rules in response to different shocks. Their paper explores desirable monetary policy rules for a small emerging economy like Pakistan.

Cavoli and Rajan (2005) consider a small open economy model of the type introduced by Ball (1999b) but with the addition of some forward-looking behavior and foreign conditions. They are comparing conventional optimal monetary policy under commitment and discretion and the variations of the simple fixed MPRs for Thailand.

Vasicek and Musil (2006) take the model of Liu (2006) and apply it on the conditions of the Czech Republic. In their model consumption contains a habit formation factor and parameters of the model are estimated by Bayesian method with Monte-Carlo simulation technique.

### 3. A Small Open Economy Model

The design of our model builds extensively on previous work done in this area, notably by Svensson (2000), Gali and Monacelli (2004), Monacelli (2005). Key aggregate relationships of our model are derived from micro-foundations with optimizing agents and rational expectations. The model consists of (i) households that supply labor, purchase goods for consumption, and hold money and bonds, (ii) firms that hire labor and produce and sell differentiated products in monopolistically competitive markets, (iii) monetary authorities and (iv) foreign economy. The variables in our model are in gaps, which are defined as deviations from equilibrium variables. The equilibrium variables are defined as levels, which will be in flexible price equilibrium.

#### 3.1 Household:

The preferences of the representative household are defined over a consumption and leisure. Household maximizes the expected present discount value of utility:

$$E_t \sum_{i=0}^{\infty} \beta^i \left[ \frac{C_{t+i}^{1-\sigma}}{1-\sigma} - x \frac{N_{t+i}^{1+\eta}}{1+\eta} \right] \quad (1)$$

Where  $1/\sigma$  is the elasticity of intertemporal substitution,  $1/\eta$  is the elasticity of labor supply,  $N_t$  is labor supply and  $C_t$  is a composite consumption index defined by:

$$C_t = \left[ (1-\gamma)^{\frac{1}{a}} (C_t^h)^{\frac{a-1}{a}} + \gamma^{\frac{1}{a}} (C_t^f)^{\frac{a-1}{a}} \right]^{\frac{a}{a-1}} \quad (2)$$

Where  $C_t^h$  is an index of consumption of domestic goods given by the CES function

$$C_t^h = \left[ \int_0^1 (c_{jt}^h)^{\frac{\theta-1}{\theta}} d_j \right]^{\frac{\theta}{\theta-1}} \quad (3) \quad \text{where } j \in [0, 1]$$

$C_t^f$  is the index of consumption of imported goods given by

$$C_t^f = \left[ \int_0^1 (c_{jt}^f)^{\frac{\theta-1}{\theta}} d_j \right]^{\frac{\theta}{\theta-1}} \quad (4)$$

$a > 0$  is the elasticity of substitution between home produced and imported goods,  $\theta > 0$  is demand elasticity of each product from its price,  $\gamma \in [0, 1]$  is the degree of openness measured as an import share in consumption.

Household maximizes utility function subject to a sequence of budget constraints of the form:

$$\int_0^1 \{P_{jt}^h C_{jt}^h + P_{jt}^f C_{jt}^f\} dj + E_t \{Q_{t,t+1} D_{t+1}\} \leq D_t + W_t N_t + T_t \quad (5) \quad \text{for } t = 0, 1, 2, \dots, \infty$$

Where  $P_{jt}^h$  and  $P_{jt}^f$  denote the prices of domestic and foreign good  $j$  respectively,  $D_{t+1}$  is the nominal payoff in period  $t+1$  of the portfolio held at the end of period  $t$  (and which includes shares in firms),  $W_t$  is the nominal wage, and  $T_t$  denotes lump-sum taxes.  $Q_{t,t+1}$  is the stochastic discount factor for one-period ahead nominal payoffs relevant to the domestic household.

The optimal allocation of any given expenditure within each category of goods yields the demand

functions: 
$$C_t^h(i) = \left( \frac{P_t^h(i)}{P_t^h} \right)^{-\theta} C_t^h \quad (6) \quad C_t^f(i) = \left( \frac{P_t^f(i)}{P_t^f} \right)^{-\theta} C_t^f \quad (7)$$

Where

$$P_t^h = \left[ \int_0^1 P_{jt}^{h^{1-\theta}} d_j \right]^{\frac{1}{1-\theta}} \quad (8) \quad P_t^f = \left[ \int_0^1 P_{jt}^{f^{1-\theta}} d_j \right]^{\frac{1}{1-\theta}} \quad (9)$$

The household's decision problem can be dealt with in tow stages. First, given the level of  $C_t$  the household chooses to buy imported and home produced goods so to minimize the cost of achieving this level of consumption.

$$P_t C_t = P_t^h C_t^h + P_t^f C_t^f \rightarrow \min$$

Subject to equation 2.

The FOC implies<sup>1</sup>:

$$C_t^h = (1-\gamma) \left( \frac{P_t^h}{P_t} \right)^{-a} C_t \quad (10) \quad C_t^f = \gamma \left( \frac{P_t^f}{P_t} \right)^{-a} C_t \quad (11)$$

Where

$$P_t = \left[ (1-\gamma)(P_t^h)^{1-a} + \gamma(P_t^f)^{1-a} \right]^{\frac{1}{1-a}} \quad (12)$$

It follows from 6 and 7 that

$$\int P_{jt}^h C_{jt}^h d_j = P_t^h C_t^h \quad \text{and} \quad \int P_{jt}^f C_{jt}^f d_j = P_t^f C_t^f \quad (13)$$

Total consumption expenditures by domestic households are given by  $P_t^h C_t^h + P_t^f C_t^f = P_t C_t$ . Thus, the period budget constraint can be rewritten as:

$$P_t C_t + E_t \{ Q_{t,t+1} D_{t+1} \} \leq D_t + W_t N_t + T_t \quad (14)$$

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<sup>1</sup> The detailed derivation of first order conditions presented in Obstfeld and Rogoff (1996), "Foundations of International Macroeconomics" and in Galí and Monacelli (2004), "Monetary Policy and Exchange Rate Volatility in a Small Open Economy".

Second, given the cost of achieving any given level of  $C_t$ , the household chooses  $C_t$  and  $N_t$  optimally.

Maximizing the utility function 1 subject to 14 yields:

$$C_t^{-\sigma} = \beta(1+i_t)E_t\left(\frac{P_t}{P_{t+1}}\right)C_{t+1}^{-\sigma} \quad (15)$$

$$\frac{xN_t^\eta}{C_t^{-\sigma}} = \frac{W_t}{P_t} \quad (16)$$

Log-linear approximation of 2, 10-12, and two FOCs 15 and 16 yields:

$$c_t = (1-\gamma)c_t^h + \gamma c_t^f \quad (17) \quad c_t^h = a\gamma\delta_t + c_t \quad (18)$$

$$c_t^f = -a(1-\gamma)\delta_t + c_t \quad (19) \quad p_t = (1-\gamma)p_t^h + \gamma p_t^f \quad (20)$$

$$c_t = E_t c_{t+1} - \left(\frac{1}{\sigma}\right)(i_t - E_t \pi_{t+1}) \quad (21) \quad \alpha_t + \eta n_t = w_t - p_t \quad (22)$$

Where lowercases denote the percentage deviations of appropriate variables from steady-state<sup>2</sup>.

We assume that in the rest of the world a representative household faces the same optimization problem with identical preferences. So the same optimality conditions hold for consumers in world economy. As the size of small economy is negligible relative to rest of the world, the latter is treated as a closed economy, so  $C_t^* = C_t^{F*}$ , and  $P_t^* = P_t^{F*}$ . Superscript \* denote foreign country.

### 3.2 Inflation, real exchange rate and terms of trade

We define the terms of trade (TOT) as:

$$TT = \frac{P_t^f}{P_t^h} \quad (23)$$

Where TT is terms of trade,  $P_t^f$  and  $P_t^h$  is domestic price of imported and home goods respectively.

Log-linearizing TOT equation and using log-linearized CPI equation (20) we get links between domestic goods inflation, CPI inflation and changes of TOT.

$$\pi_t = \pi_t^h + \gamma\Delta\delta_t \quad (24)$$

$$\Delta\delta_t = \pi_t^f - \pi_t^h \quad (25)$$

Where  $\delta_t$  is the percentage deviation of TOT from steady state and  $\Delta$  denotes first difference. We maintain the assumption that the law of one price (LOP) holds for the export sector, but incomplete pass-through for imports is allowed. We define the real exchange rate and the law of one price (LOP) gap as:

<sup>2</sup> Throughout the model lowercases, denote the percentage deviations of appropriate variables from steady state.

$$\psi_t = \frac{S_t P_t^*}{P_t^f} \quad (26)$$

$$Q_t = \frac{S_t P_t^*}{P_t} \quad (27)$$

Where  $Q$  is real exchange rate,  $S$  is nominal exchange rate (AMD/US) and  $P^*$  is foreign price index.

Log-linearizing these two equations around steady state and using equation (25) one can write

$$q_t = s_t + p_t^* - p_t = \psi_t + (1-\gamma)\delta_t \quad (28)$$

$$\psi_t = s_t + p_t^* - p_t^f \quad (29)$$

### 3.3 *Uncovered interest rate parity*

Under the assumption of complete international financial markets and perfect capital mobility, the expected nominal return from risk-free bonds, in domestic currency terms, must be the same as the expected domestic-currency return from foreign bonds. As in Armenia we have imperfect capital mobility and for international investors Armenia has some degree of risk, uncovered interest parity holds with risk premium.

$$\Delta s_{t+1} = i_t - i_t^* + \lambda_t \quad (30)$$

Where  $\lambda$  is risk premium that requires investors for investing in Armenian currency,  $i_t^*$  and  $i_t$  are foreign and home nominal interest rate respectively. We are going to separate the  $\lambda$  into three parts. The main part is autoregressive process, second one depends on gap of remittances<sup>3</sup> and the last part is defined as a shock, which has zero mean.

### 3.4 *International risk sharing*

Under the assumption of complete international financial markets and perfect capital mobility we have the following:

$$E_t R_{t,t+1} = E_t \left( R_{t,t+1}^* \frac{S_{t+1}}{S_t} \right) \quad \text{where} \quad R_{t,t+1} = 1 + i_t \quad R_{t,t+1}^* = 1 + i_t^* \quad (31)$$

Using this relationship, we can equate the inter-temporal optimality conditions for the domestic and foreign households' optimization problem:

$$\beta E_t \left\{ \frac{P_t}{P_{t+1}} \left( \frac{C_{t+1}}{C_t} \right)^\sigma \right\} = \beta E_t \left\{ \frac{P_t^*}{P_{t+1}^*} \frac{S_{t+1}}{S_t} \left( \frac{C_{t+1}^*}{C_t^*} \right)^\sigma \right\} \quad (32)$$

<sup>3</sup> This kind approach discussed also in Poghosyan, T., Kocenda, E. and P. Zemcik (2008), "Modeling Foreign Exchange Risk Premium in Armenia", *Emerging Markets Finance and Trade*, 44(1): pp. 119-136.

The following relationship must hold in equilibrium:

$$C_t = \vartheta C_t^* Q_t^{\frac{1}{\sigma}} \quad (33)$$

Where  $\vartheta$  is some constant depending on initial asset positions. Log-linearization equation 33 around the steady gives:

$$c_t = c_t^* + \frac{1}{\sigma} q_t \quad (34), \quad \text{or using equation 28}$$

$$c_t = c_t^* + \frac{1-\gamma}{\sigma} \delta_t + \frac{1}{\sigma} \psi_t \quad (35)$$

### 3.5 Firms

There is a continuum of identical monopolistically-competitive firms which have the following production function.

$$Y_t = Z_t N_t \quad (36),$$

Where  $Z_t$  is total productivity and  $z_t = \log(Z)$  is assumed to follow AR(1) process

$$z_t = \rho_z z_t + \xi_t^z, \text{ where } 0 \leq \rho_z \leq 1 \text{ is parameter of persistency and } \xi_t^z \text{ is an i.i.d shock.}$$

Assuming symmetric equilibrium for all  $j$  firms, log-linear approximation of aggregate production is

$$y_t = z_t + n_t \quad (37)$$

From the firms cost minimization problem we have equation for marginal cost which is the same for all firms.

$$MC_t = \frac{W_t}{P_t^h Z_t} \quad (38)$$

$$mc_t = w_t - p_t^h - z_t \quad (39)$$

### 3.6 Price setting behavior

In the domestic goods market monopolistic firms are allowed to set prices according to a Calvo-staggered manner. Every period only  $1-w_h$  of domestic firms are able to reset their prices optimally, where  $0 \leq w_h \leq 1$ , while the other  $w_h$  part of the domestic firms can not. We only consider the symmetric equilibrium case where  $P_{t,j}^h = P_{t,k}^h; \quad \forall J, K$  so we can drop the index  $J$ . Let  $\bar{P}_t^h$  denote the price

level that optimizing firms set each period. Then the aggregate domestic price level will evolve according to:

$$p_t^h = w_h p_{t-1}^h + (1 - w_h) \bar{p}_t^h \quad (40)$$

When setting a new price,  $\bar{p}_t^h$ , in period  $t$ , an optimizing firm will seek to maximize the current value of its dividend stream subject to the sequence of demand constraints. In aggregate the following function is maximized:

$$\max_{\bar{p}_t^f} \sum_{k=0}^{\infty} w_h^k E \{ \beta^k Q_{t,t+k} [Y_{t+k} (\bar{p}_t^h - mc_t^N)] \} \quad (41), \text{ where } Q_{t,t+k} = \left( \frac{C_{t+k}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+k}}$$

$$s.t \quad Y_{t+k} \leq \left( \frac{\bar{p}_t^h}{P_t} \right)^{-\eta} C_t^h \cdot C_t^{1-\eta} \quad (42)$$

The optimal price-setting strategy for the typical firm resetting its price in period  $t$  can be approximated by the (log-linear) rule<sup>4</sup>:

$$\pi_t^h = \beta E_t(\pi_{t+1}^h) + \lambda_{\pi} \hat{mc}_t \quad (43) \quad \lambda_{\pi} = \frac{(1 - w_h)(1 - w_h \beta)}{w_h}$$

Where  $\hat{mc}$  is the deviation of real marginal cost from steady state,  $\beta$  is discount factor and  $w_h$  measures the degree of rigidity, which shows the probability that firm can not adjust its price.

We assume that the LOP holds at the wholesale level for imports. However, inefficiency in distribution channels together with monopolistic retailers keep domestic import prices over and above the marginal cost. As a result, the LOP fails to hold at the retail level for domestic imports. Following a similar Calvo-pricing procedure it is possible to derive the price setting behavior for the domestic importers<sup>5</sup>.

$$\pi_t^f = \beta E_t(\pi_{t+1}^f) + \lambda_f \psi_t \quad (44) \quad \lambda_f = \frac{(1 - w_f)(1 - w_f \beta)}{w_f}$$

Where  $w_f$  measures the degree of rigidity for importer.

The detailed derivation of price setting behavior of domestic importer presented in Appendix A.

<sup>4</sup> The detailed derivation of price setting rule is presented in Galí and Monacelli (2004) and in Walsh (2003).

<sup>5</sup> The Philips curve for importers derived in Monacelli (2005).

### 3.7 Equilibrium

#### 3.7.1 Demand Block

The goods market equilibrium condition implies that domestic output is equal to the sum of domestic and foreign consumption of home produced goods:

$$y_t = kc_t^h + (1-k)c_t^{h*} \quad (45)$$

Where  $y_t$  is aggregate demand and  $k$  is the share of domestic demand in the total demand.

We can write foreign country analogy of equation 19 as follows:

$$c_t^{*h} = a^*(\delta_t + \psi_t) + c_t^* \quad (46)$$

As foreign economy too large compare to our economy we assume that  $c_t^* = y_t^*$  and foreign economy variables must be taken as exogenous<sup>6</sup>.

Substituting equation 18 and 24 into 21 and making forward iteration on it we can write:

$$c_t^h = \lim_{\tau \rightarrow \infty} c_{t+\tau}^h - \frac{1}{\sigma} \rho_t - \left(a - \frac{1}{\sigma}\right) \gamma \left[ \lim_{\tau \rightarrow \infty} \delta_{t+\tau} - \delta_t \right] \quad (47) \text{ where } \rho_t \equiv \sum_{\tau} (i_{t+\tau} - \pi_{t+\tau+1}^h)$$

$\rho$  is approximately the product of the long real interest rate.

Let us assume that there is a steady state for  $c_t^h$ ,<sup>7</sup> then  $\lim_{\tau \rightarrow \infty} c_{t+\tau}^h = 0$  and assuming that  $\lim_{\tau \rightarrow \infty} \delta_{t+\tau} = 0$

we can write the equation 47 as follows:

$$c_t^h = -\left(\frac{1}{\sigma}\right) \rho_t + \left(a - \frac{1}{\sigma}\right) \gamma \delta_t \quad (48)$$

Using 45, 46 and 48 yields:

$$y_t = -\frac{k}{\sigma} \rho_t + (1-k)y_t^* + \left(\frac{c_1}{\sigma}\right) \delta_t + (1-k)a^*\psi_t \quad (49)$$

where  $c_1 = k\gamma(\alpha - 1) + (1-k)\alpha^*$

#### 3.6.2 Supply Block

From firms optimization problem we have that real marginal cost is equal to:

$$\hat{mc}_t = w_t - p_t^h - z_t = w_t - p_t + p_t - p_t^h - z_t = \sigma c_t + \eta n_t + \gamma \delta_t - z_t = \sigma c_t + \eta y_t + \gamma \delta_t - (1+\eta)z \quad (50)$$

<sup>6</sup> For more details see S. Schmitt-Grohe and M. Uribe (2003).

<sup>7</sup> This assumption presumes that net foreign assets are stationary. Thus we avoid the well-known problem that a small open economy with infinitely-lived consumers that can borrow at an exogenous world interest rate normally has non-stationary net foreign assets (and consumption). Such non-stationarity generally violates the assumption of an exogenous world interest rate, since the economy may become arbitrary large.



Using equations 35 and 50 we can find:

$$\hat{mc}_t = \eta y_t + \sigma y_t^* + \delta_t + \psi_t - (1 + \eta)z_t \quad (51)$$

As in the flexible price equilibrium  $\hat{mc}$  is 0, we can write:

$$\bar{y}_t = \frac{(1 + \eta)}{\eta} z - \frac{\sigma}{\eta} y_t^* + \frac{1}{\eta} \bar{\delta}_t \quad (52)$$

Where  $\bar{y}$  is deviation of the flexible price output from steady state and  $\bar{\delta}$  is deviation of the flexible price terms of trade from steady state.

### 3.6.3 Aggregate demand and output

In this section, we summaries linearized equilibrium aggregate demand and supply blocks of the model in terms of variables deviation from flexible price levels. This representation of the model will serve us for analyzing monetary policy with different type of the shocks.

Combining 49 and 52 yields:

$$y\_gap_t = -\frac{k}{\sigma} r\_gap_t + \frac{c_1}{\sigma} \delta\_gap_t + (1 - k)a^* \psi_t \quad (53)$$

Where  $y\_gap = y - \bar{y}$ ,  $\delta\_gap = \delta - \bar{\delta}$ ,  $r\_gap = r - \bar{r}$  and

$$\bar{r} = \frac{\sigma}{k} \left[ \frac{\sigma + \eta(1 - k)}{\eta} y_t^* - \frac{(1 + \eta)}{\eta} z_t + \frac{\sigma + \eta c_1}{\sigma \eta} \bar{\delta}_t \right] \quad (54)$$

Where  $\bar{r}$  is the policy natural real rate of interest.

Taking into account the effects of remittances mentioned above, we exogenously add the gap of remittances to the equation 53. The coefficient of remittances in output gap equation is equal to remittances/GDP ratio.

$$y\_gap_t = -\frac{k}{\sigma} r\_gap_t + \frac{c_1}{\sigma} \delta\_gap_t + (1 - k)a^* \psi_t + c_2 tr\_gap_t \quad (55)$$

Where  $tr\_gap$  is gap of remittances.

The intuition behind this equation is that the coefficient of real interest rate depends on inter-temporal elasticity of substitution reduced by export share. The coefficient of TOT consists of two parts: substitution between imported and domestic goods and change in export demand. The coefficient of LOP gap shows the change in export demand as a result of incomplete pass-through.

Using 28 and 30 equations and assuming flexible price equilibrium we can write

$$\Delta \bar{\delta}_{t+1} = 1/(1-\gamma) * (\bar{r}_t - r_t^* + \lambda_t) \quad (56)$$

### 3.6.4 Marginal cost and inflation dynamics

Using 51 and 52 yields:

$$mc = \eta y\_gap_t + \delta\_gap_t + \psi_t \quad (57)$$

Combining 43 and 57 we can write aggregate supply equation.

$$\pi_t^h = \beta E_t(\pi_{t+1}^h) + \lambda_\pi \eta y\_gap_t + \lambda_\pi \delta\_gap_t + \lambda_\pi \psi_t \quad (58)$$

The coefficient of  $y\_gap$  declines if the degree of rigidities and monopolistic power of firms rises.

### 3.6.5 Foreign variables

We assume that foreign inflation, foreign output, foreign interest rate and foreign exchange risk premium follow stationary univariate AR (1) processes.

$$\pi_t^* = \phi_\pi^* \pi_{t-1}^* + \varepsilon_t^{\pi^*} \quad (59)$$

$$y_t^* = \phi_y^* y_{t-1}^* + \varepsilon_t^{y^*} \quad (60)$$

$$i_t^* = \phi_i^* i_{t-1}^* + \varepsilon_t^{i^*} \quad (61)$$

$$\lambda_t^* = \phi_\lambda^* \lambda_{t-1}^* + \varepsilon_t^{\lambda^*} \quad (62)$$

Where the coefficients are nonnegative and less than unity and the shocks are zero-mean i.i.d. These specifications of the exogenous variables are chosen for simplicity.

In general  $\rho_t$  and  $q_t$  are closely related with each other. Substituting  $q_t$  from 28 into 30 and making forward iteration on it we can write:

$$q_t = -\rho_t + \sum_{\tau=0}^{\infty} (i_{t+\tau}^* - \pi_{t+\tau+1}^* + \lambda_{t+\tau}) \quad (63)$$

By using 59-62 and exploiting the sum of a geometric series we have:

$$\rho_t = -q_t + \frac{\phi_i^*}{1-\phi_i^*} i_{t-1}^* - \frac{\phi_\pi^*}{1-\phi_\pi^*} \pi_t^* + \frac{\phi_\lambda^*}{1-\phi_\lambda^*} \lambda_{t-1} \quad (64)$$

### 3.8 *Monetary policy*

All real-world inflation targeting is flexible inflation targeting. Flexible inflation targeting means that monetary-policy objectives include not only stability of inflation around the inflation target but also stability of the real economy, such as stability of the output gap. This can conveniently be expressed as a conventional quadratic loss function.

$$L_t = (\pi_t - \pi^{tar})^2 + \mu_y y_{-gap_t}^2 + \mu_s \Delta s_t^2 \quad (65)$$

$\mu_y > 0$  and  $\mu_s > 0$  denotes the relative weights on output-gap stabilization and exchange rate smoothing relative to inflation stabilization. The central bank may also be concerned about variability of instrument-rate changes, which would correspond to additional term.

The corresponding inter-temporal loss function in period  $t$  can then be written as the sum of current and expected discounted future losses.

$$E_t \sum_{i=0}^{\infty} \beta^i L_{t+i} \quad (66)$$

In the model, the instrument of monetary policy is a short term interest rate. The policy design problem then is to specify how to adjust interest rate given current stage of economy and future projection, taking into account the fact that private sector behavior doesn't depend only on current interest rate setting, but on the expected future course of monetary policy. Generally speaking, the monetary policy rule (MPR) can be derived in two ways. The first is to specify a simple MPR for the instrument that provides guidance for the monetary authority in setting monetary policy. Second, the MPR could be formally derived from explicit optimization of a central bank's loss function.

The optimal rule under commitment is in general function of all state variables in the model. To use such rule in practice is very hard because of its complexity and lack of tractability. Such type of very complex rule is hard to explain to Bank Board as well as to communicate with public. Therefore in our analysis we focus on the practical aspects of rule implementation and using optimal simple rule, which specify the reaction of the interest rate as a function of a few macroeconomic variables. We rely on targeting rule approaches as Svensson (2000, 2003) and set inflation-forecast based on the simple rule as a short term interest rate reaction function. For our model we consider that the monetary policy response is described by the following interest rate rule:

$$i_t = b_1 i_{t-1} + (1 - b_1) \left[ \bar{i} + a_1 (\pi_t - \pi^{tar}) + a_2 y\_gap_t + a_3 (s_t - s_{t-1}) \right] \quad (67)$$

Where  $\bar{i}$  is the equilibrium nominal interest rate and  $\pi^{tar}$  is the inflation target. The coefficient  $b_1$  is the degree of the central bank willingness to smooth interest rate,  $a_1$ ,  $a_2$  and  $a_3$  are the relative weights on inflation forecast, output gap and exchange rate stabilization.

### 3.9 Model solution

Our macroeconomic system of equations (20), (25), (28), (30), (44), (54-56), (58-62), (64) and (67) can be expressed in State-Space form as follows:

$$\begin{bmatrix} X_{t+1} \\ Cx_{t+1/t} \end{bmatrix} = AZ_t + \begin{bmatrix} v_{t+1} \\ 0 \end{bmatrix}$$

Where  $Z_t = (X'_t, x'_t)'$ ,  $X_t$  is the vector of predetermined state variables,  $x_t$  is the vector of forward-looking variables,  $v_t$  is the vector of innovations to the predetermined state variables and C and A are matrixes of appropriate dimensions.

We are going to utilize the Generalized Schur (QZ) Decomposition in solving Rational Expectations models. In particular, this approach is useful even when the matrix C is singular.

## 4. Calibrating the model and model property

### 4.1 Stylized facts on long-term trends

Long-term patterns in the data are important for model design and calibration.

In this section, we review the long-term trends that we consider most relevant from the perspective of building a general equilibrium model of monetary transmission (graphs presented in Appendix B).

The Armenian economy has experienced high growth rates since 1998, which turned to double-digit growth since 2002 and was mostly driven by high growth of non-tradable sectors of the economy, especially the construction sector (figure 5 BC I, 1).

The most significant factor contributing to high growth in construction and thus to the whole economy is the huge inflow of private and public transfers and remittances (figure 5 BC I, 2).

Persisting growth rates of financial inflows to Armenia have fostered the appreciation of the exchange rate (figure 5 BC I, 3), which has lowered inflation to a certain extent (taking into consideration price

rigidities in the import sector), while on the other hand, worsened the competitiveness of domestic firms.

Trends of deteriorating competitiveness of domestic firms have lowered the share of tradable sector of the economy, resulting in a higher import/export ratio (Figure 3 MLT III, 3).

High economic growth recorded during these years continued due to increased domestic demand, which has been the case from 2003. In the structure of domestic demand, the growth rate of capital investment has kept on moving faster than consumption (Figure 4 MLT IV, 1) reflecting the acceleration of the growth rate of construction on the aggregate supply side. As for private or household consumption, the growth rate has been mainly constant and has not much changed inversely in response to real interest rate movements (Figure 6 BC II, 3), which shows that inter-temporal substitution is very low.

The large amount of financial inflows along with the global US dollar depreciation and monopolized non-optimal import demand has resulted in a certain appreciation of real and nominal exchange rates since 2003. There is evidence of deepening appreciation since 2004, which is mainly determined by the huge inflow of remittances (Figure 5 BC I, 3).

Since 2005, the CBA has intervened (buying foreign currency) in the foreign exchange market heavily, especially in 2007, although the Armenian dram has steadily appreciated (Figure 3 MLT III, 1). The main objective of intervening was to neutralize the supply of foreign currency entering the market due to de-dollarization. Doing so, the CBA has not increased the effective money supply, but it only replaced the foreign currency denominated part by the domestic currency. In order to avoid additional inflationary pressures the CBA has never tried to sterilize foreign currency supply from the remittances side. The de-dollarization process started in Armenia in the second half of 2004. At that time, the share of foreign currency deposits in total deposits was around 75 percent (Figure 3 MLT III, 2), while currently it accounts for 35 percent due to acceleration of de-dollarization.

Terms of trade have begun to deteriorate starting at the end of 2001 (Figure 1 MLT I, 3) remaining around a constant before that period resulting in high growth rate of export as well as import prices. Downward trends of post-2001 are characterized by faster growth of export prices versus import prices. Especially, growth rate of prices of precious and semi-precious stones, copper and molybdenum have

begun to climb. In 2006 the TOT have improved due to increased prices of oil products, natural gas, grain and granulated sugar, while growth rates of prices for copper and molybdenum slowed down.

As for inflation it has not obviously followed the exchange rate behavior (Figure 7 BC III, 1), which suggests that there is an incomplete exchange rate pass-through to inflation, although the share of imported goods in CPI accounts for approximately 30%.

## 4.2 Calibration

We parameterize the model using both more formal economic criteria and calibration approaches. We choose the model parameters to achieve realistic dynamic properties and a reasonable match between the model's implied business cycle correlations and those observed in the data.

Our model has the following structural and derived parameters presented in Table 1:

Table 1: Descriptions and restrictions of the structural and derived parameters

Parameter	Description	Restriction
$\alpha$	elasticity of substitution between home produced and imported goods	$\alpha \neq 0$
$\gamma$	degree of openness measured as an import share in consumption	$\gamma \in [0, 1]$
$\beta$	discount factor	$0 < \beta \leq 1$
$1/\sigma$	elasticity of intertemporal substitution	$1/\sigma \neq 0$
$1/\eta$	elasticity of labor supply	$1/\eta \neq 0$
$w_h$	degree of rigidity for domestic firms	$0 \leq w_h \leq 1$
$w_f$	degree of rigidity for importer	$0 \leq w_f \leq 1$
$k$	share of domestic demand in the total demand	$0 \leq k \leq 1$
$\alpha^*$	elasticity of substitution between home and imported goods for foreign country	$\alpha^* \neq 0$

We take into account the structural parameters that have been used in other developing and transition countries presented in Table 2.

Table 2: Structural parameters by Countries

	$\alpha$	$\gamma$	$\sigma$	$\eta$	$w_h$	$w_f$
New Zealand	1		1	1	0.5	0.5
Czech	1	0.4	1	1	0.5	0.5
Romania	-	0.37	1.1	0.5	0.75	0
Brazil	-	-	6.4	2.1	0.66	0
Colombian	1.28	-	0	1.6	-	-
Pakistan	2	0.2	5	1	-	-

For calibration of elasticity of substitution between home produced and imported goods we use the logarithmic form of equation 11:

$$a = \frac{\log(\gamma) + \log(C) - \log(C^f)}{(1 - \gamma) \log(TT)} \quad (68)$$

Average calculated value of  $a$  from 2000 is around 1.5 (Figure 8 in Appendix C), which is consistent with theoretic restriction and with Ostry and Reinhart's (1992) results of estimation of the elasticity of substitution between non-tradable and importable goods for a sample of developing countries. Therefore, for elasticity of substitution between home produced and imported goods we choose 1.5.

We use the share of imported goods in CPI 0.25 as the degree of openness  $\gamma$ .

The elasticity of intertemporal substitution between current and future consumptions  $1/\sigma$  calibrated based on Euler equation from household optimization, which declares:

$$\sigma = \frac{\log(\beta) + r_t}{\log(C_{t+1}) - \log(C_t)} \quad (69)$$

As household's intertemporal utility discount factor  $\beta$  is empirically close to one, it makes  $\log(\beta) = 0$ . The average share of real interest rate in consumption change from 2001 is around 4 (Figure 8 in Appendix C), and becomes 3.5 when removing two peaks from the data.

As for the elasticity of labor supply  $\eta$ , it is set to be higher than one to ensure good model properties.

As mentioned in Tevosyan (2006) the expected time between price adjustments in the Armenian economy is 3 quarters, which corresponds to 0.66 of probability of price re-optimization. Therefore, both  $w_h$  and  $w_f$  are chosen to be 0.66.

The share of domestic demand in the total demand on average was 0.8 since 2000 (Figure 9 in Appendix C).

For simplicity, we choose the elasticity of substitution between home and imported goods for foreign country the same as for domestic economy. The calibration of deep parameters is presented in Table 3.

Table 3: The values of the deep parameters

Parameter	Value
$a$	1.5
$\gamma$	0.25
$\beta$	0.99
$\sigma$	3.5
$\eta$	1.1
$w_h$	0.66
$w_f$	0.66
$k$	0.8

$a^*$	1.5
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We estimate the autoregressive coefficients using historical data since 1998, with quarterly frequencies.

The estimation results are presented in the Table 4.

Table 4: Autoregressive Coefficients<sup>8</sup>

$0 \leq \rho_z \leq 1$	AR of domestic productivity	0.54 [3.8]
$0 \leq \phi_\pi^* \leq 1$	AR of foreign inflation	0.46 [3.2]
$0 \leq \phi_y^* \leq 1$	AR of foreign output	0.49 [3.7]
$0 \leq \phi_i^* \leq 1$	AR of foreign interest rate	0.9 [14]
$0 \leq \phi_\lambda^* \leq 1$	AR of foreign exchange risk premium	0.36 [2.6]
$0 \leq \phi_r \leq 1$	AR of remittances	0.46 [3.2]

Note that domestic productivity, foreign output and foreign interest rate have relatively long memory process than the foreign inflation, foreign exchange risk premium and remittances.

### 4.3 Impulse Responses

In this section, we use model calibration and equilibrium conditions derived above to characterize and discuss the dynamic effects of temporary shocks. Each of the model's temporary innovations is shocked by an unexpected one-percentage point change in the first period of the simulation. The graphical results of impulse responses are presented in Appendix D

#### *Domestic productivity shock*

The results of domestic productivity shock in the model produce similar trade-offs as in Monacelli (2005). The rise in the relative productivity of the domestic economy tends to lower the output gap and to exert a downward pressure on domestic inflation. However it also implies a nominal depreciation and a rise in the LOP gap. Any attempt to stabilize the output gap by lowering interest rates would then boost the nominal depreciation and therefore imply a further rise in the LOP gap. Therefore, the monetary authority cannot simultaneously stabilize the domestic markup and the law of one price. The

<sup>8</sup> In brackets are values of "T" statistics.



interesting aspect of this result is that this trade-off arises endogenously in response to productivity shocks.

The next trade-off that monetary authorities face under incomplete pass-through is that they cannot simultaneously stabilize CPI inflation and output gap. The raised LOP gap increases imported inflation which in some degree increases CPI inflation. Again any attempt to stabilize output gap by reducing interest rate will generate nominal depreciation and increase LOP gap.

*Domestic price mark-up shock*

Following the domestic cost-push shock, the domestic inflation rate rises, driving up headline inflation. Monetary policy raises interest rates in response to rising inflation, which bring real exchange rate appreciation. However, the cost-push shock also induces intra-temporal expenditure switching from domestic to imported goods. Because of this switching process, the demand for imported goods raises causing nominal exchange rate depreciation. The depreciated nominal exchange rate pushes up LOP gap and inflation of imported goods. Owing to rigidities in imported sector, the imported inflation is quite low compared with domestic inflation, therefore the TOT improves significantly. Combining effects of positive real interest rate gap and negative TOT gap generate a negative output gap, which brings the increased domestic inflation back. Economic stabilization works through the real marginal cost and lasts about three and a half years.

*Domestic demand shock*

The shock temporarily increases the output over its potential level driving domestic marginal cost up. Increased marginal cost raises domestic inflation. Monetary authorities raise the interest rate as a reaction to output gap shock, which brings to both real and nominal exchange rate appreciation. Because of higher domestic inflation, we get negative TOT gap. The increased real interest rate gap and decreased TOT gap reduce aggregate demand and close output gap. The economy reaches its equilibrium after three years through reduction of aggregate demand.

*Policy shock*

The shock assumes that the monetary authority temporarily deviates from its rule by unexpectedly raising policy rates. Following a domestic monetary policy shock, the domestic nominal interest rate demonstrates an immediate increase, which increases real interest rate gap and generates exchange rate appreciation. Positive interest rate gap reduces domestic inflation through a reduction of output gap.

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Appreciated nominal exchange rate causes imported good prices fall. Economic stabilization works through the interest rate, with gradual decline generating an easy condition in terms of trade and output recovery bringing inflation back.

#### *Import price shock*

Higher prices for imported goods imply a rise of substitution from imported to domestic goods resulting in increased prices for domestic goods. The monetary authority reacts to this situation by raising the policy rate, which contributes to formation of a negative output gap and appreciation in the real exchange rate. Decreasing output gap and appreciated exchange rate bring the domestic and imported inflation back.

#### *Foreign demand shock*

Increase in foreign demand raises the real equilibrium interest rate and decreases the equilibrium level of terms of trade. Combined effects of easy conditions in both real interest rate and terms of trade sides hike the aggregate demand increasing domestic inflation. Monetary policy reacts to the higher inflation and output gap by increasing policy rate, which reduces aggregate demand and generates exchange rate appreciation. Appreciated exchange rate creates negative LOP gap and reduces prices of imported goods.

Further decreases of TOT and interest rate gaps combined with negative LOP gap close the output gap and restore the equilibrium.

#### *Real exchange rate shock*

Positive real exchange rate shock drives nominal exchange rate to appreciate, which creates positive LOP gap and TOT gap. Increased LOP gap gives rise to both imported inflation and domestic inflation through output gap.

As a reaction to this shock, the monetary authority increases the interest rate; this causes nominal appreciation and positive real interest rate gap. Real interest rate gap restricts aggregate demand, while appreciated currency brings LOP gap back and the equilibrium recovers.

#### *Foreign exchange risk premium shock*

Risk premium shock has an impact on the economy through real exchange rate and long run real interest rate equilibrium level.

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Positive risk premium shock generates positive real interest rate gap and exchange rate depreciation. Imported goods become expensive because of a depreciated exchange rate, which creates substitution from imported to domestic goods. The substitution generates inflationary pressures on domestic prices. To stabilize the economy the monetary authority increases policy rate significantly, and this produces a negative output gap and brings inflation to the equilibrium.

*Up to now, the results of the model have the same intuition as in the standard small open economy models, which are used for both theoretical perspectives and empirical analyses. The results can vary in terms of size of variable changing, time horizon needed for achieving equilibrium or in terms of variability of macroeconomic indicators. These variations are mainly due to different calibration results.*

*The next section discusses the impulse response results of shock to real remittances gap that provides a more accurate explanation of current developments in the Armenian economy.*

#### *Real remittances gap shock*

The interesting aspect of this shock is the simultaneous existence of a negative TOT gap, positive output gap and deflation of domestic prices because of unexpected increase in remittances. We cannot find similar patterns in the results of other shocks. The intuition of remittances gap shock is as follows: The tradable sector of the economy suffers from deteriorating competitiveness, while non-tradable sector benefits from a higher demand coming from remittances side. Moreover, the benefit of non-tradable sector is higher compared with the losses of the tradable sector. This situation accurately describes the recent developments in the Armenian economy. Since 2002, the Armenian economy has been growing by about 13 percent on average. The volume of remittances has tripled and the national currency appreciated by more than 40 percent. Under these circumstances, the main driving force for economic growth can be and actually was the non-tradable sector. It contributed to GDP growth more than 60 percent, 42 percent of which was only the share of construction. The trade balance worsens by 26 percent per year on average.

In the model, all these trends show up only by introducing remittances, and none of the standard shocks is able to describe Armenia's economic situation in the last several years. It is worth emphasizing the role of remittances in the model in order to bring the model results closer to the current economic situation in Armenia and get scenarios that are more efficient for monetary policy actions.

#### **4.4 Verification of model calibration**

This section presents the results of estimation of structural shocks and VAR analysis, which serves for verification of model calibration.

The structural shocks are the differences of actual path of endogenous variables and the paths of the endogenous variables derived from a dynamic simulation of the model given the actual in sample realization of exogenous variables. The goal is to test the ability of the model to replicate the paths of the endogenous variables, given the ex-post evolution of the exogenous variables. As far as our model contains rational expectations, we cannot just take the paths of the exogenous variables as given, because it will mean that economic agents know the paths of the exogenous variables in advance. In order to simulate the model, we take the values of the exogenous variables as known only after their realization. As for the endogenous variables, the simulation is dynamic, which means that the results of the forecast, obtained in each period for these variables, serve as input for the forecast of the next period. In contrast, the simulation for the exogenous variables is static: the actual values, in each period, serve as the input for the next period.

Figures 10 and 11 in Appendix E present the results of estimated structural shocks by both models with and without remittances for the period of 2001-2006.

Figure 10 shows that while home and imported inflations and LOP gap are tracked to a reasonable degree of accuracy, the output gap is not explained to a satisfactory extent.

Furthermore, the equation for the exchange rate suffers from the lowest explanatory power.

The model explains the nominal exchange rate through the expected exchange rate and the nominal interest rate differential between home and foreign countries with the addition of a risk premium. Considerably weak explanatory power of UIP equation indicates that interest rate differentials provide only a partial explanation for exchange rate fluctuations and do not take into account the balance of payment shocks, which subsist in Armenian economy during the simulation period.

Figure 11 shows that the model with remittances improves explanatory power of output gap equation. The improvement in this simulation is evidence of the significant influence of the remittances on domestic demand in Armenia during the simulation period. The introduction of remittances only has effect on the structural shocks of output gap and UIP equations, because in the process of estimation of structural shocks we take the actual values of right hand side variables and remittances are only in these

two equations. The effect of remittances on UIP equation is smaller due to the forward-looking nature of UIP equation.

We run a simple VAR to see whether the model-produced impulse responses are consistent with the impulse responses generated by the actual data or not. Given the relatively small data set available, we choose to run VAR only with three variables: output gap, inflation and real exchange rate gap. In the meantime, we face a trade-off between the interest rate and exchange rate. We could not take both of them because the optimal lag length is more than 8, while we have insufficient number of observations. Taking into account the fact that the exchange rate channel is much stronger than the interest rate channel in Armenia, we finally choose to use the real exchange rate. The VAR analysis suggests that the model-produced impulse responses are consistent with those derived from VAR (the impulse responses of VAR analysis and results of some tests presented in Appendix F).

## 5. Optimal simple monetary policy rule

As discussed in section 3.8, the direct optimal-control approach with a once-and-for-all calculation of the optimal reaction function and then a commitment to this reaction function is impracticable. Therefore, in our analysis we rely on the targeting rule and set inflation-forecast based on the simple rule as a short-term interest rate reaction function (equation 67). The reaction function 67 is quite general. In Table 5, we present some specific cases of 67. From the presented reaction functions, we will choose that one which is more desirable for our economy and is optimal for the given class of reaction functions (the solution algorithm is described in Soderlind (1999)).

Table 5: Cases of reaction functions

Strong inflation targeting	$b_1 \geq 0$	$a_1 \neq 1$	$a_2 = 0$	$a_3 = 0$
Output stabilization	$b_1 \geq 0$	$1 \neq a_1 \neq a_2$	$a_2 \neq 0$	$a_3 = 0$
Exchange rate smoothing	$b_1 \geq 0$	$a_1 \neq 1$	$a_2 = 0$	$a_3 \neq 0$
Output stabilization with exchange rate smoothing	$b_1 \geq 0$	$a_1 \neq 1$	$a_2 \neq 0$	$a_3 \neq 0$

The traditional criterion for evaluating different monetary policy rules is based on a loss function that increases in measures of inflation variability and output gap. If there is fear of floating, the loss function would also be positively related to exchange rate variability. Indicators based on these types of criteria were used to explore desirability of interest rate rules described in Table 5.

For baseline analysis of performance of monetary policy rules we choose the parameters presented in Table 6.

Table 6: Baseline parameterization

Strong inflation targeting	$b_1 = 0.5$	$a_1 = 2.5$	$a_2 = 0$	$a_3 = 0$
Output stabilization	$b_1 = 0.5$	$a_1 = 1.5$	$a_2 = 0.5$	$a_3 = 0$
Exchange rate smoothing	$b_1 = 0.5$	$a_1 = 1.5$	$a_2 = 0$	$a_3 = 0.5$
Output stabilization with exchange rate smoothing	$b_1 = 0.5$	$a_1 = 1.5$	$a_2 = 0.5$	$a_3 = 0.5$

For all types of rules, we set the interest rate smoothing parameter to equal 0.5 to reflect the CBA's willingness to keep the policy rate smoother due to a less developed financial system.

The relative performance of different rules depends on what type of shocks affect the economy. To highlight this link, we are going to present the results of simulations based on one shock at a time. For each simulation, we compare the performance of alternative policy rules using variability for key macroeconomic variables and loss function value.

A wide variety of external and internal shocks can be added to the model. Here we highlight five shocks, which appear to be especially important for the Armenian economy. These shocks are; a financial shock to the uncovered interest rate parity, a real shock to domestic productivity, a real shock to foreign output, a real shock to domestic demand, and a real shock to remittances.

The relative performance of interest rate rules presented in Appendix G

The results of simulations with all shocks show that the lowest value of loss function was reached with strong inflation targeting (SIT) rule. Indeed, as the tables show, the stronger inflation targeting rule leads to lower standard deviations of both the inflation rate and output gap, but generates the highest variation for exchange rate and LOP gap. This fact can distress the Armenian economy, because it has a higher degree of dollarization and more than 40 percent of population receives foreign currency denominated remittances from abroad.

Taking into account this fact we believe that for Armenian economy the exchange rate smoothing (ERS) rule is more desirable. ERS rule has relatively low value of loss function and less variability in exchange rate and LOP gap compared with SIT rule.

Here we should mention that the results depend on the weights of loss function also. In this paper, we do not analyze the effect of different weights on performance of interest rate rules, which could be the interesting topic for the further research.

After determining the class of the reaction function, the second step is to determine the numerical values of its parameters, which minimize the loss function. Table 7 presents the simulation results of our model using ERS rule with different numerical values of its parameters.

Table 7: Simulation results with different parameters of ERS rule

Rule			Loss Function
b1	a1	a3	$\mu_y = 0.5 \quad \mu_s = 0.2$
0.5	1.5	0.5	0.1273
0.5	1.5	1	0.12490
0.5	1.5	1.5	0.12680
0.5	2.5	1	0.11310
0.5	3.5	1	0.10710
0.5	5	1	0.10220
0.5	7.5	1	0.09830
0.5	8.5	1	0.09750
0.5	11	1	0.09650
0.5	12	1	0.09640
0.5	13	1	0.09650
0.5	12	2	0.09910

From the table we can see that for a given degree of interest rate smoothing the minimum value of the loss function achieves with the following numerical parameters of ERS rule:

$$i_t = 0.5 * i_{t-1} + (1 - 0.5) * \left[ \bar{i} + 12 * (\pi_t - \pi^{tar}) + (s_t - s_{t-1}) \right] \quad (70)$$

## 6. Sensitivity Analysis

Recall that the reduced form parameters are complicated functions of the structural parameters. Therefore, when there is a change in a structural parameter, all of the reduced form parameters change simultaneously and thus affect the propagation mechanism of any structural shock. Specifically, we vary some of the structural parameters in the aggregate supply and demand equations and see how the performance of difference interest rate rules react to this change. The range of values for this analysis was chosen from the confidence interval of the empirical distribution of the structural parameters and theoretical restrictions. We believe that this exercise provides more information than a simple

calibration exercise, where lack of knowledge about the estimated value of the parameters can make the impulse responses highly misleading.

### **6.1 *Changes in degree of rigidity***

According to the theoretical restriction, the degree of rigidity could be between zero and one. According to our calibration result, it is equal to 0.66, assuming that firms keep prices unchanged for three quarters. We analyze the performance of difference MPRs both with higher and lower degrees of rigidity compared to the calibrated value. We choose 0.85 as a higher degree of rigidity, which assumes that prices adjust after one and a half years. For a lower value of degree of rigidity, we choose 0.35, which means that firms change their prices every one and a half quarters. The performance of MPRs with higher degree of rigidity did not change significantly compared to the baseline scenario. The SIT rule ensures the lowest value of loss function, but generates a higher variability in exchange rate and LOP gap behavior. Exchange rate smoothing rule has relatively low value of loss function and less variability in exchange rate and LOP gap compared with the SIT rule.

In case of lower degree of rigidity, the picture changes a little bit. Since Armenia is a small open economy and assuming that prices are more flexible, the effect of shocks, especially external shocks, on the exchange rate will be higher. Therefore, in this framework the ERS rule ensures the lowest value of loss function.

### **6.2 *Changes in private sector behavior***

Now we proceed with analyzing the impact of changes in some private sector structural parameters on the performance of MPRs. According to the results of empirical estimation, the most probable interval for  $\sigma$  is  $[2 ; 4]$ . Our calibrated value of  $\sigma$  is 3.5, which is quite high. Now we analyze the performance of MPRs with  $\sigma = 2$ , which assumes that the output gap reacts significantly to the monetary policy shock. The analysis shows that the results of performance of different MPRs are not sensitive to the variation of elasticity of inter-temporal substitution.

Finally, we perform an analogous analysis around the calibrated parameter  $\alpha$ . We calibrate elasticity of substitution between domestically produced and imported goods to be equal to 1.5. For sensitivity analysis we choose  $\alpha = 1$ , which assumes less substitution between domestic and imported goods with



respect to terms of trade shock compared to our calibration. The results of performance of MPRs with lower  $\alpha$  show the same picture as in the case with baseline calibration.

## **7. Conclusion and Policy recommendations**

In this paper, we developed a simple New Keynesian type open economy model with micro-foundations, which can serve as an efficient tool for monetary policy analysis and inflation targeting.

Impulse response and model in-sample simulation results show that introducing of real remittances gap brings value added to the model properties. While the standard shocks in the model create responses of main macroeconomic variables similar to the standard New Keynesian models, none of them are similar to the recent economic developments in Armenia. Only the shock to remittances is able to highlight the recent developments. In addition to this, the model in-sample simulation results suggest that introduction of real remittances gap improves the explanatory power of the aggregate demand equation. The model calibration is verified by estimated structural shocks and comparison with simple VAR model of Armenian economy. The results of estimated structural shocks show that model with remittances was able to replicate the actual path of endogenous variables, given the model calibration and in-sample actual realization of exogenous variables.

The comparison of impulse responses produced by the model and those generated by VAR advocates that the responses to the same shock are similar in both cases.

The ERS rule is considered more desirable for Armenia, although the SIT rule ensures the lowest value of loss function. The analysis shows that the SIT rule generates higher volatility in the exchange rate, while ERS rule ensures less volatility of exchange rate and relatively low value of loss function. As far as avoiding excessive exchange rate fluctuations is an important goal for emerging economies, strong inflation response is considered as undesirable. The further evaluation of ERS rule demonstrates that quite aggressive response to inflation is needed for achieving minimum value of the loss function given to our model and the class of monetary policy rule.

According to the sensitivity analysis, our results are relatively robust. The results are not highly sensitive to the changes of elasticity of inter-temporal substitution and elasticity of substitution between home produced and imported goods. Higher degree of rigidity does not have a significant effect on the

performance of the different types of interest rate rules, while the ERS rule ensures the lowest value of loss function due to lower degree of rigidity.

## Appendixes

### ***Appendix A: Derivation of price setting behavior for the domestic importers***

When firm  $j$  setting a new price in period  $t$ , it seeks to maximize the present value of its dividend stream subject to the demand constraints:

$$\max_{\bar{P}_t^f} \sum_{k=0}^{\infty} w_f^k E \left\{ \beta^k Q_{t,t+k} \left[ C_{t+k}^f (\bar{P}_t^f - S_{t+k} P_{t+k}^*) \right] \right\} \quad (A1), \text{ where } Q_{t,t+k} = \left( \frac{C_{t+k}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+k}}$$

$$s.t \quad C_t^f = \gamma \left( \frac{\bar{P}_t^f}{P_t} \right)^a C_t \quad (A2)$$

Where  $\bar{P}_t^f$  is the price set by a firms adjusting its price in period  $t$ .

The first order condition implies:

$$\sum_{k=0}^{\infty} (w_f \beta)^k E \left\{ \left( \frac{C_{t+k}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+k}} \left[ \bar{P}_t^f - \frac{a}{1-a} [S_{t+k} P_{t+k}^*] \right] C_{t+k} \right\} = 0 \quad (A3)$$

Making some mathematical transformation we can write the equation A3 as follows:

$$\sum_{k=0}^{\infty} (w_f \beta)^k E \left\{ \left( \frac{C_{t+k}}{P_{t+k}} \right)^{-\sigma} P_{t-1}^f \left[ \frac{\bar{P}_t^f}{P_{t-1}^f} - \frac{a}{1-a} \frac{P_{t+k}^f}{P_{t-1}^f} \frac{[S_{t+k} P_{t+k}^*]}{P_{t+k}^f} \right] C_{t+k} \right\} = 0 \quad (A4)$$

Log-linerizing the equation A4 around symmetric steady state and using definition of LOP gap we can write the optimal price setting rule for domestic importers:

$$\bar{p}_t^f = p_{t-1}^f + \sum_{k=0}^{\infty} (\beta w_f)^k E \pi_{t+k}^f + (1 - \beta w_f) \left\{ \sum_{k=0}^{\infty} (\beta w_f)^k E \psi_{t+k} \right\} \quad (A5)$$

We can write the equation A5 in this form:

$$\bar{p}_t^f - p_{t-1}^f = \beta w_f (\bar{p}_{t+1}^f - p_t^f) + \pi_t^f + (1 - \beta w_f) \psi_t \quad (A6)$$

Under the assumption of Calvo type price-setting, the dynamics of the aggregate price index for imported goods has the following form:

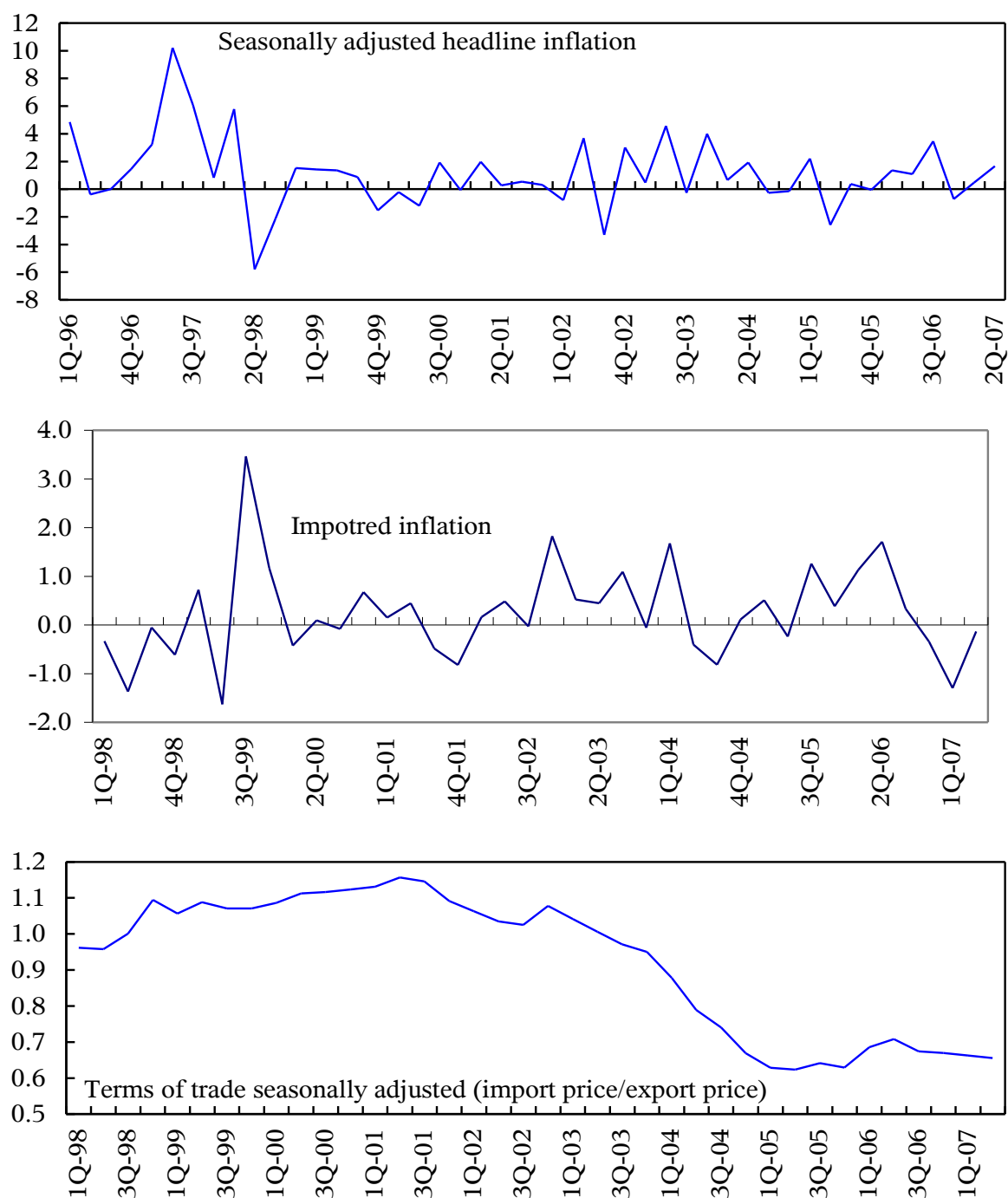
$$p_t^f = w_f p_{t-1}^f + (1 - w_f) \bar{p}_t^f \quad (A7)$$

Combining the equations A6 and A7 yields the inflation adjustment equation for domestic importers:

$$\pi_t^f = \beta \pi_{t+1}^f + \frac{(1 - w_f)(1 - w_f \beta)}{w_f} \psi_t \quad (A8)$$

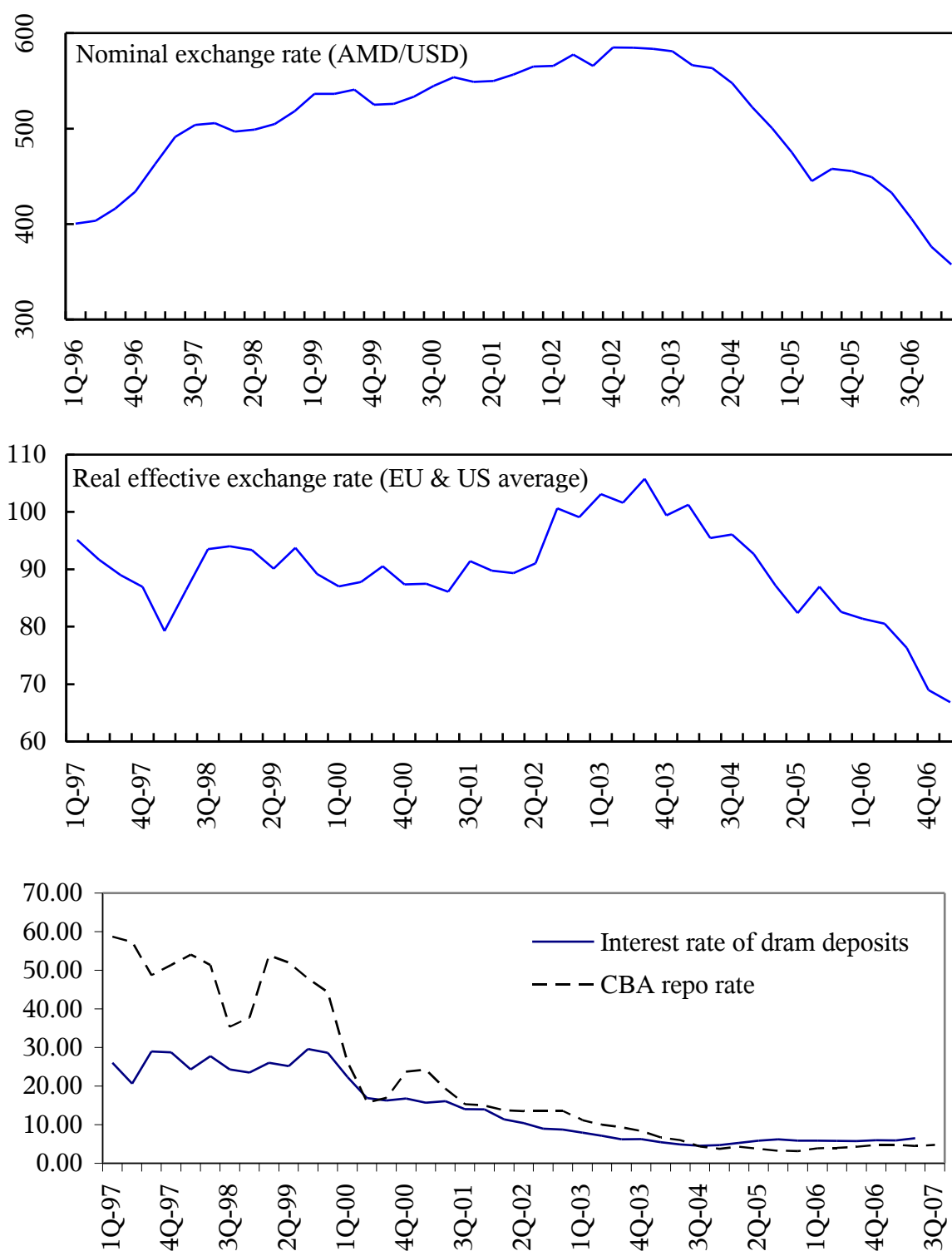
***Appendix B: Main long-term trends and business cycle fluctuations in Armenian economy***

Figure 1. Armenia: Main Long-term trends I



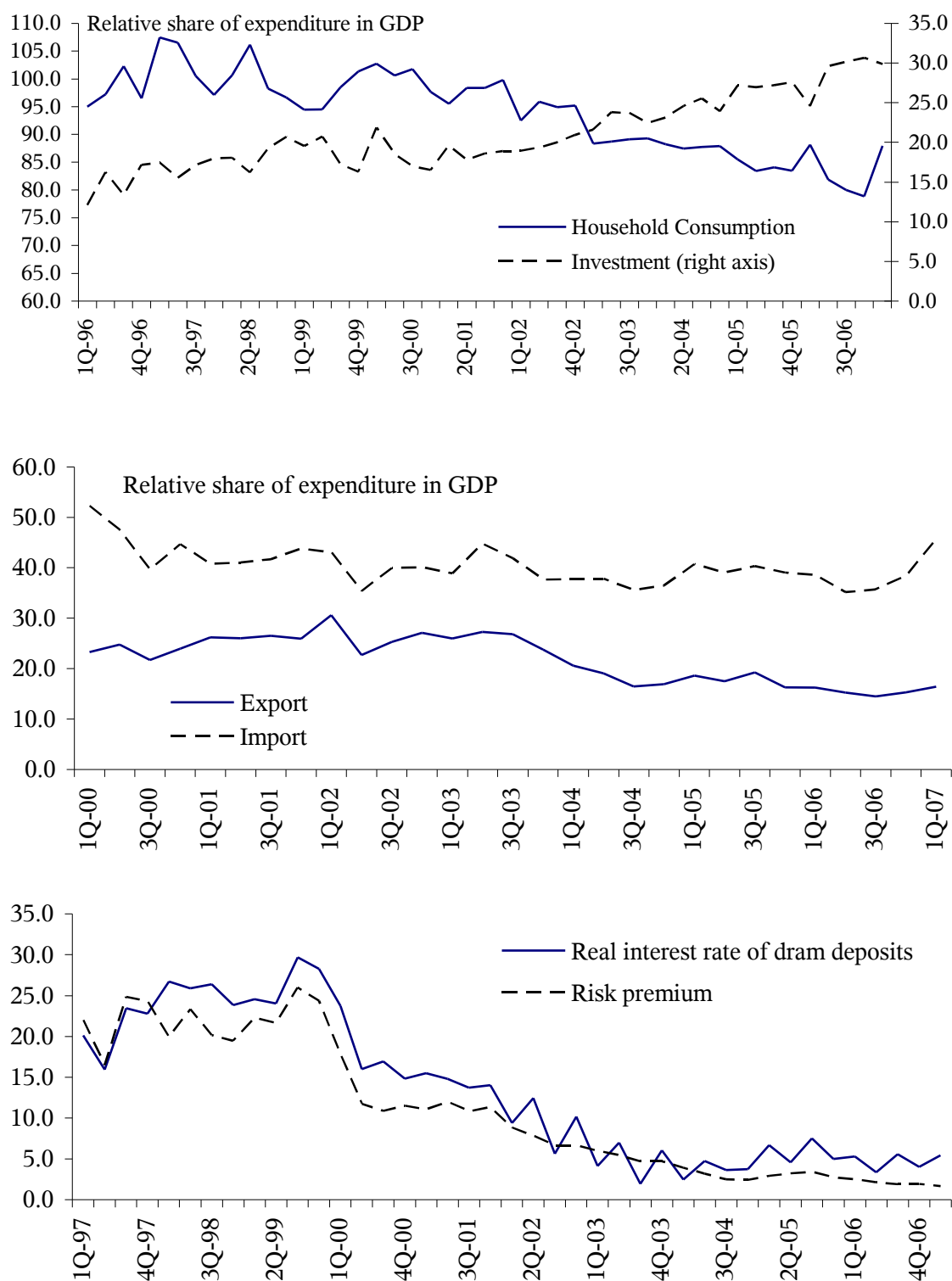
Source: National Statistical Service of Armenia, Central Bank of Armenia, Authors estimates

Figure 2. Armenia: Main Long-term trends II



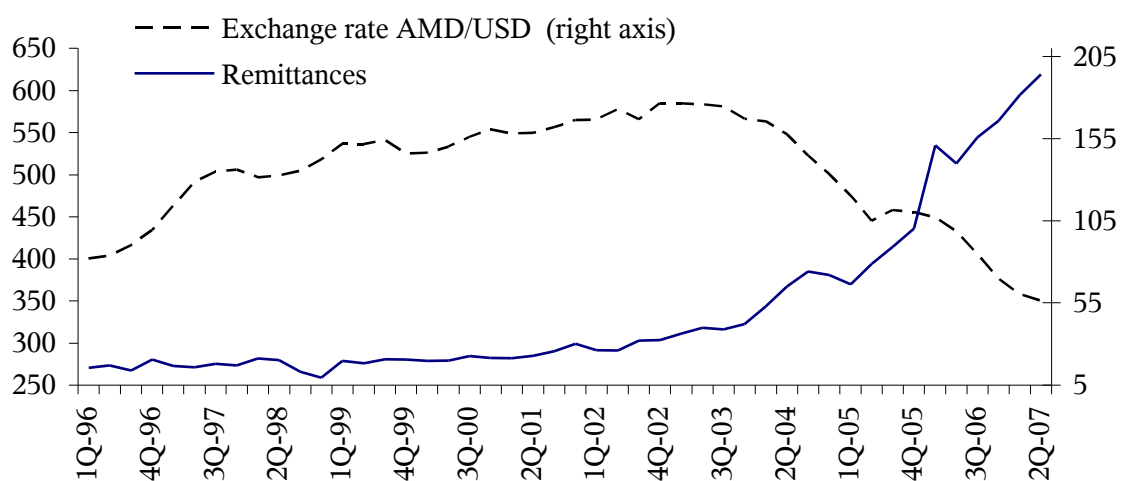
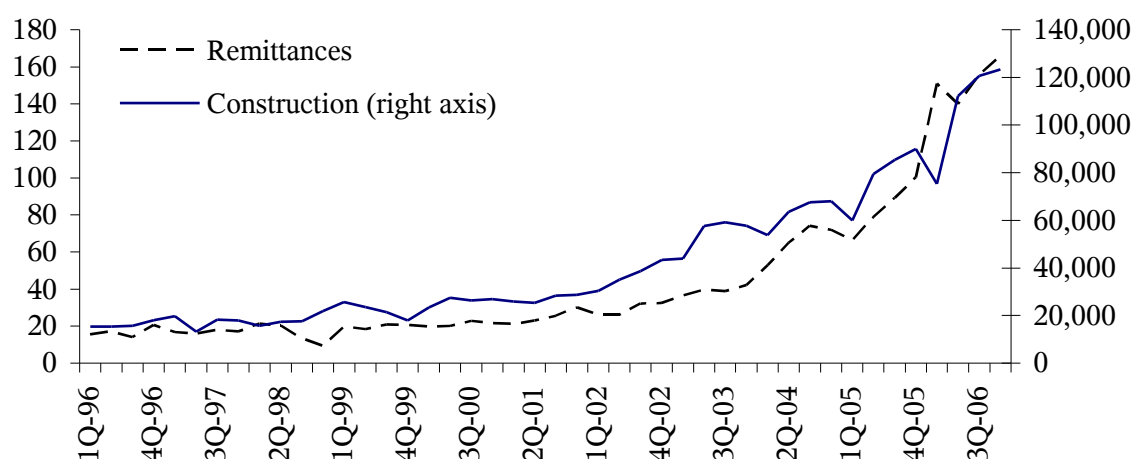
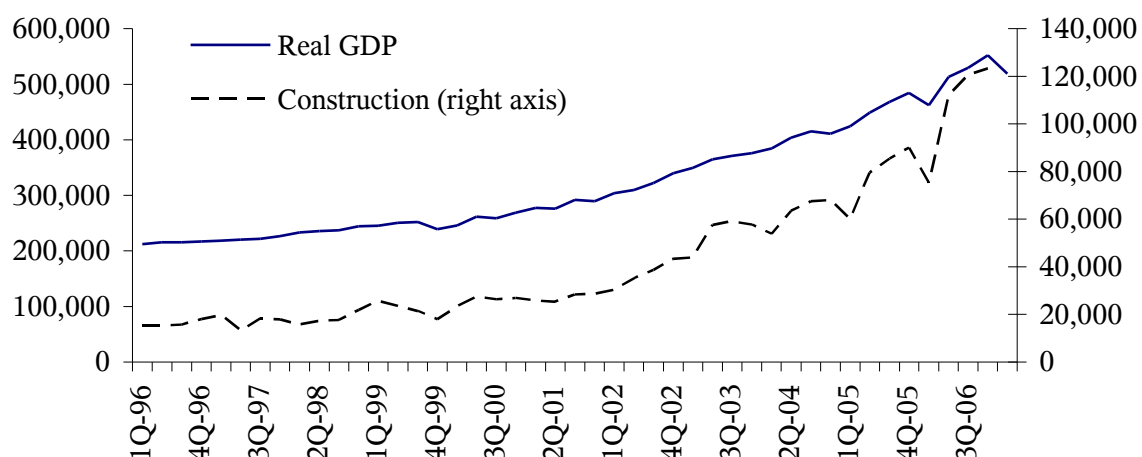
Source: National Statistical Service of Armenia, Central Bank of Armenia, Authors estimates

Figure 4. Armenia: Main Long-term trends IV



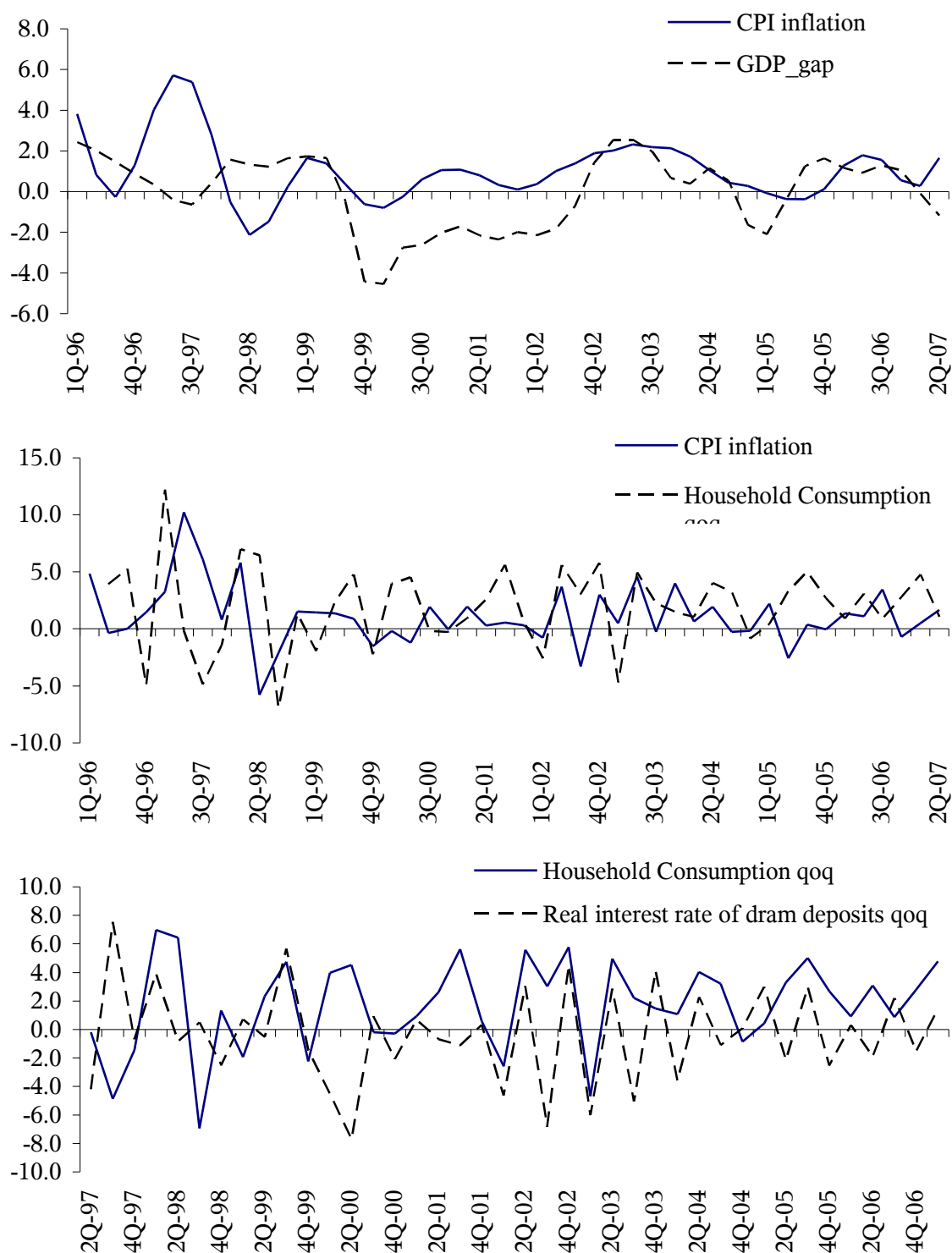
Source: National Statistical Service of Armenia, Central Bank of Armenia, Authors estimates

Figure 5. Armenia: Business Cycle Fluctuations I I



Source: National Statistical Service of Armenia, Central Bank of Armenia, Authors estimates

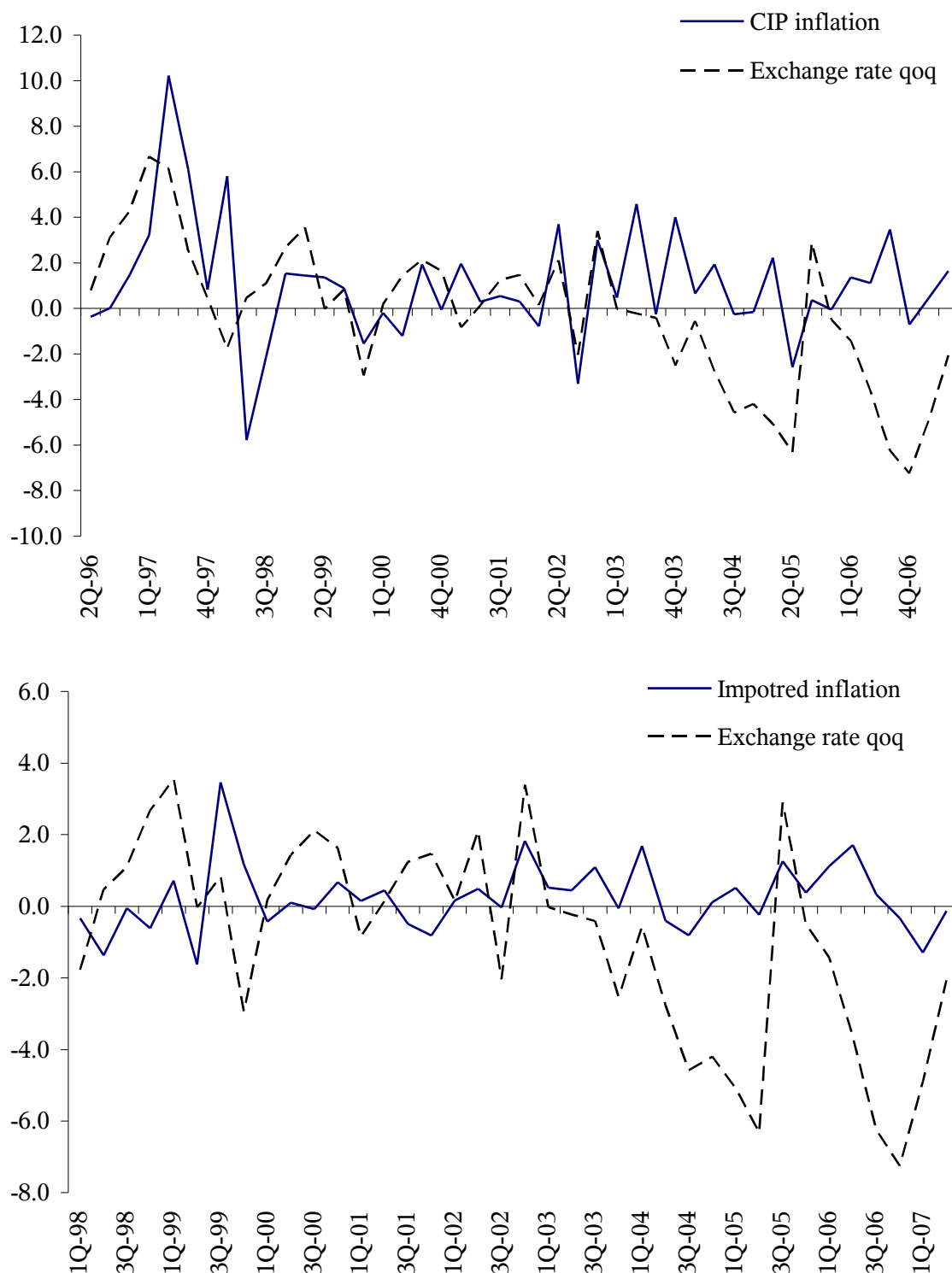
Figure 6. Armenia: Business Cycle Fluctuations II



Source: National Statistical Service of Armenia, Central Bank of Armenia, Authors estimates



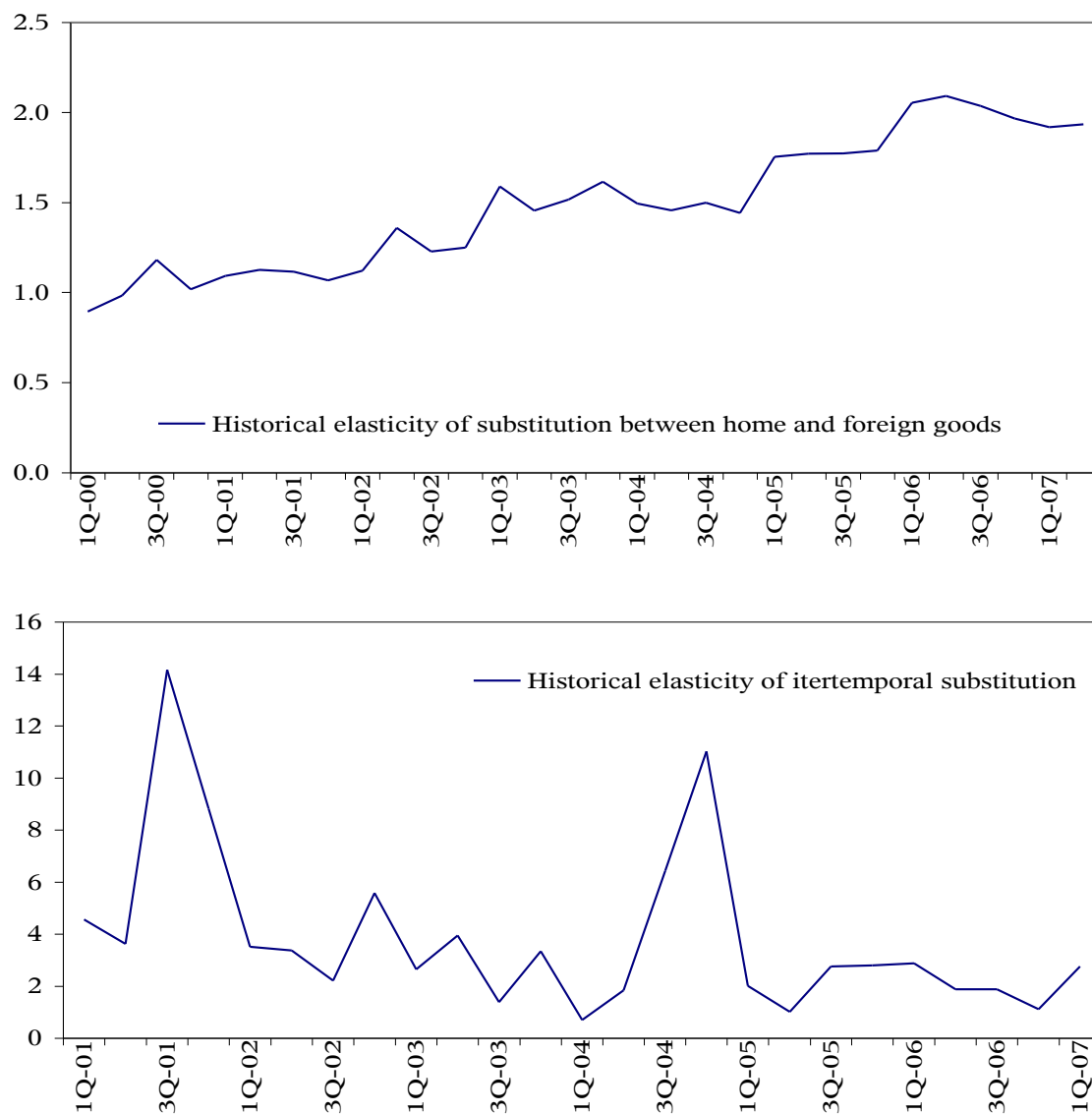
Figure 7. Armenia: Business Cycle Fluctuations III



Source: National Statistical Service of Armenia, Central Bank of Armenia, Authors estimates

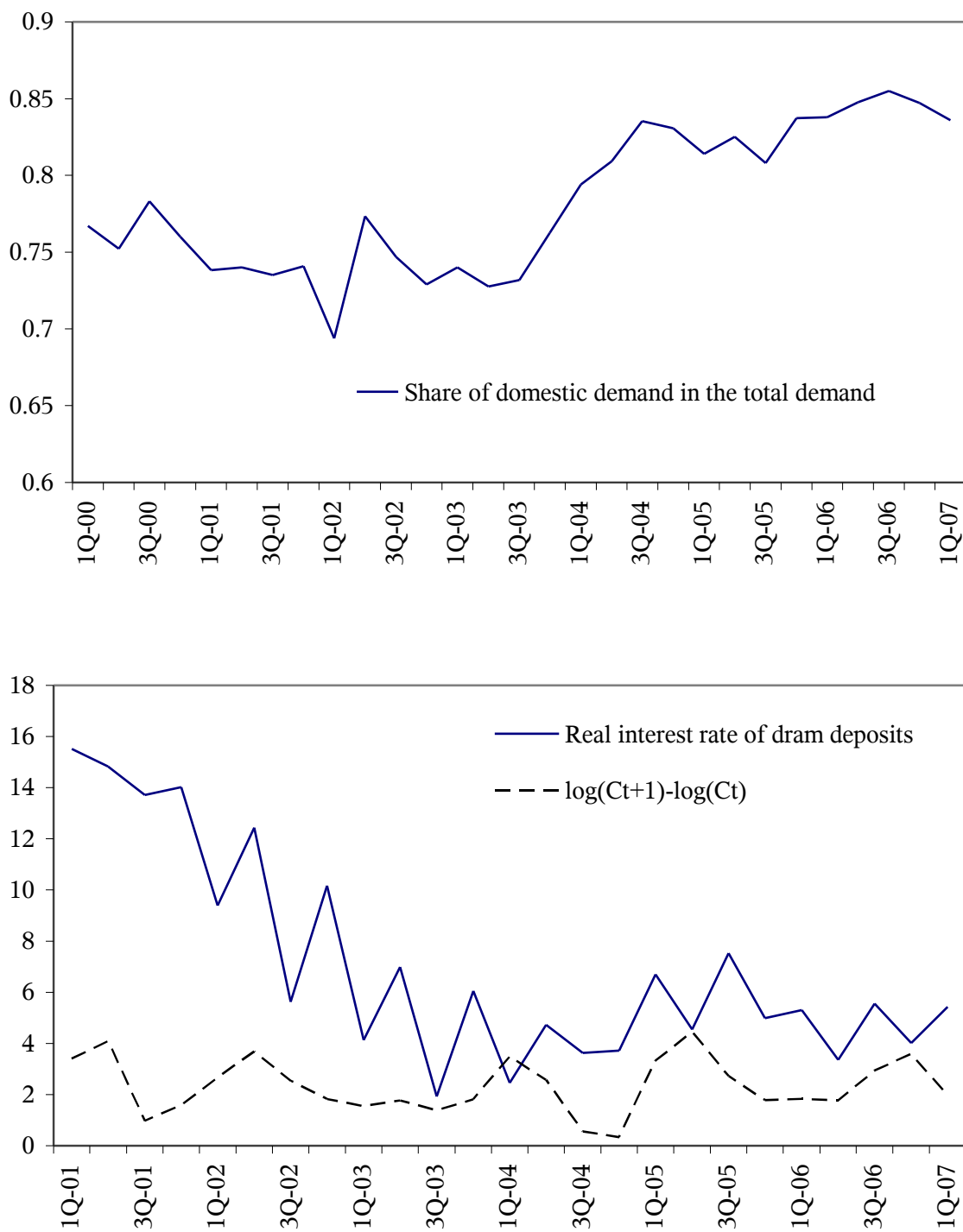
### Appendix C: Calibration of the model's structural parameters

Figure 8. Armenia: Calibration of Model's Structural Parameters



Source: National Statistical Service of Armenia, Authors estimates

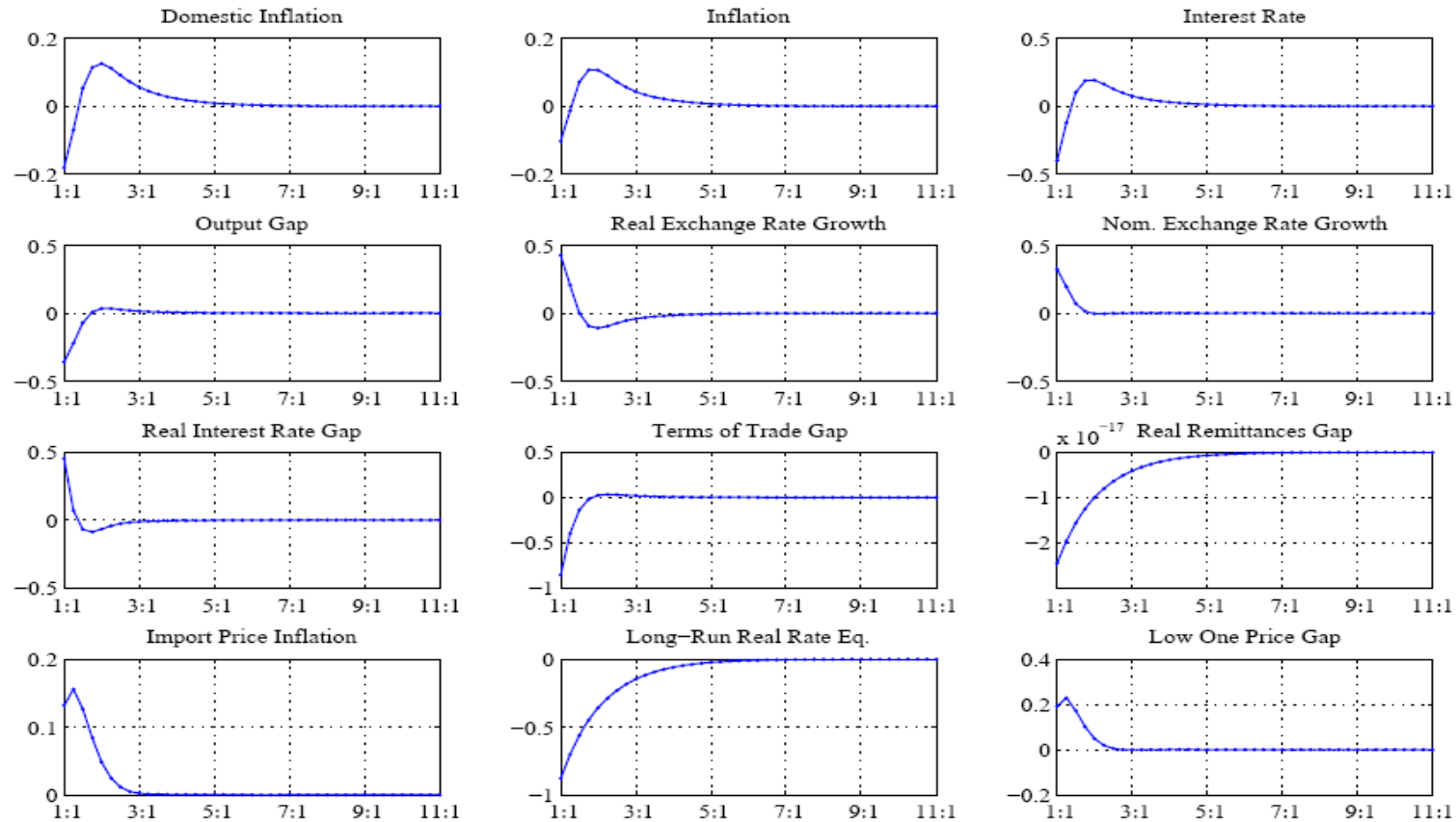
Figure 9. Armenia: Calibration of Model's Structural Parameters



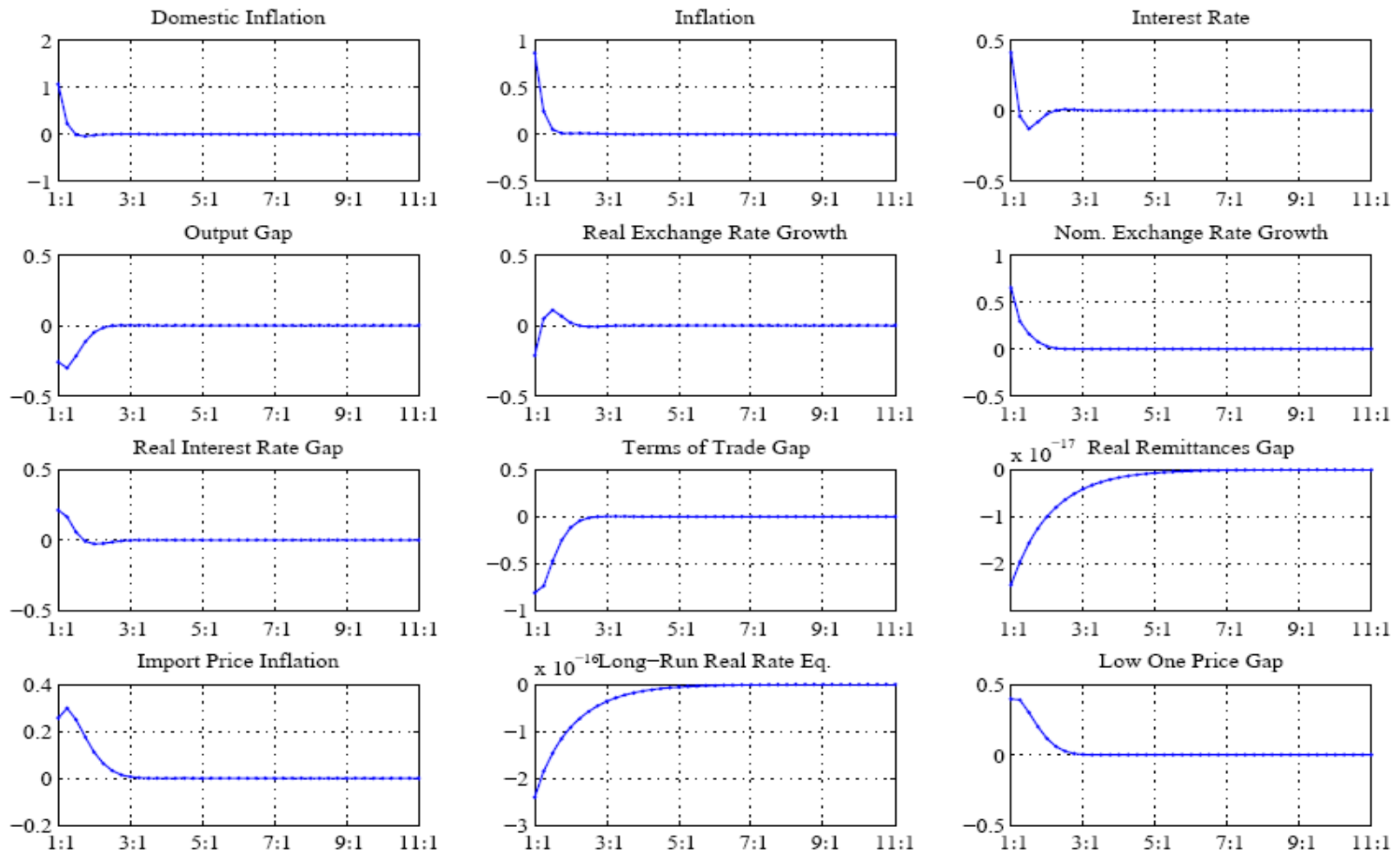
Source: National Statistical Service of Armenia, Authors estimates

***Appendix D: Impulse responses of the model***

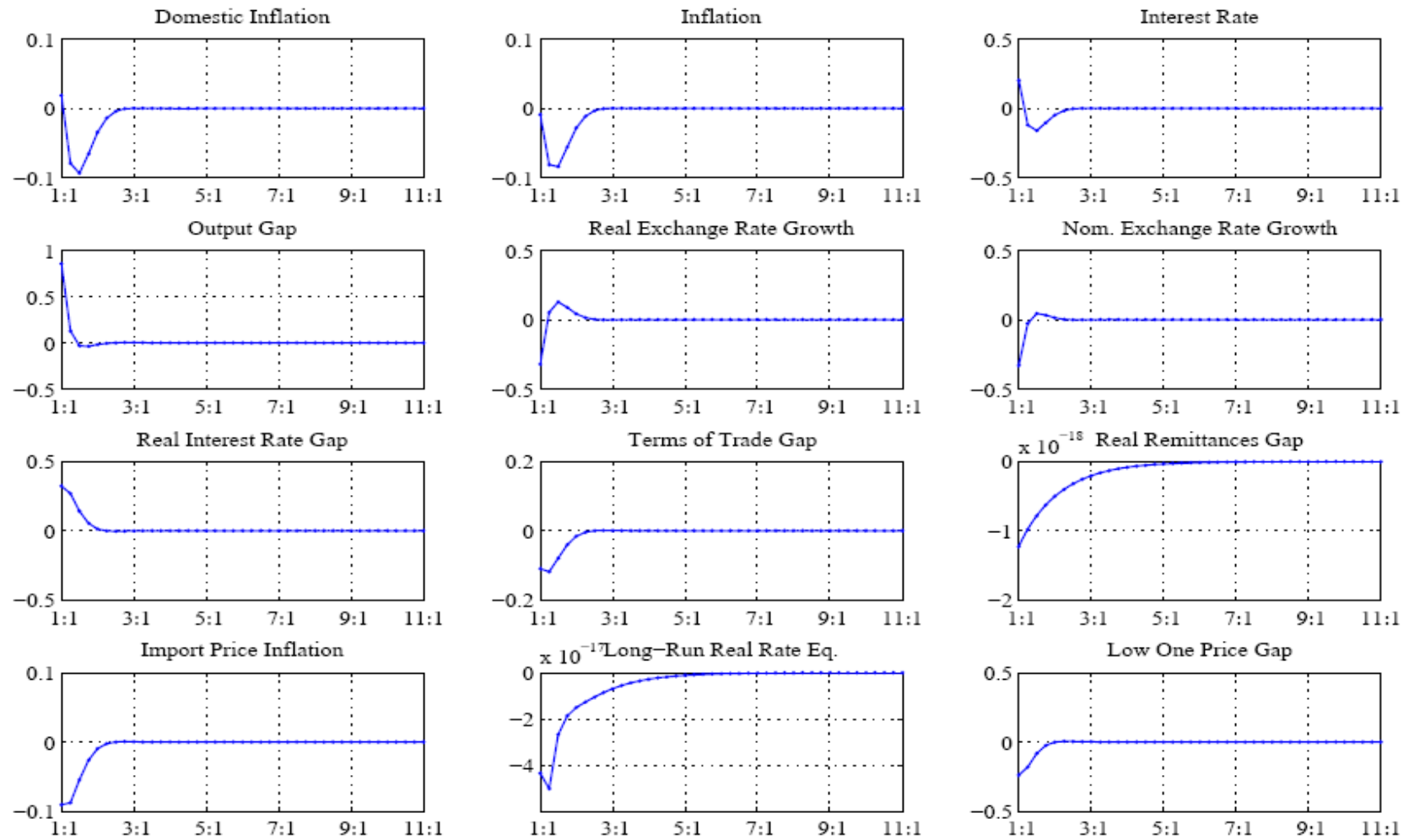
**Productivity Shock**



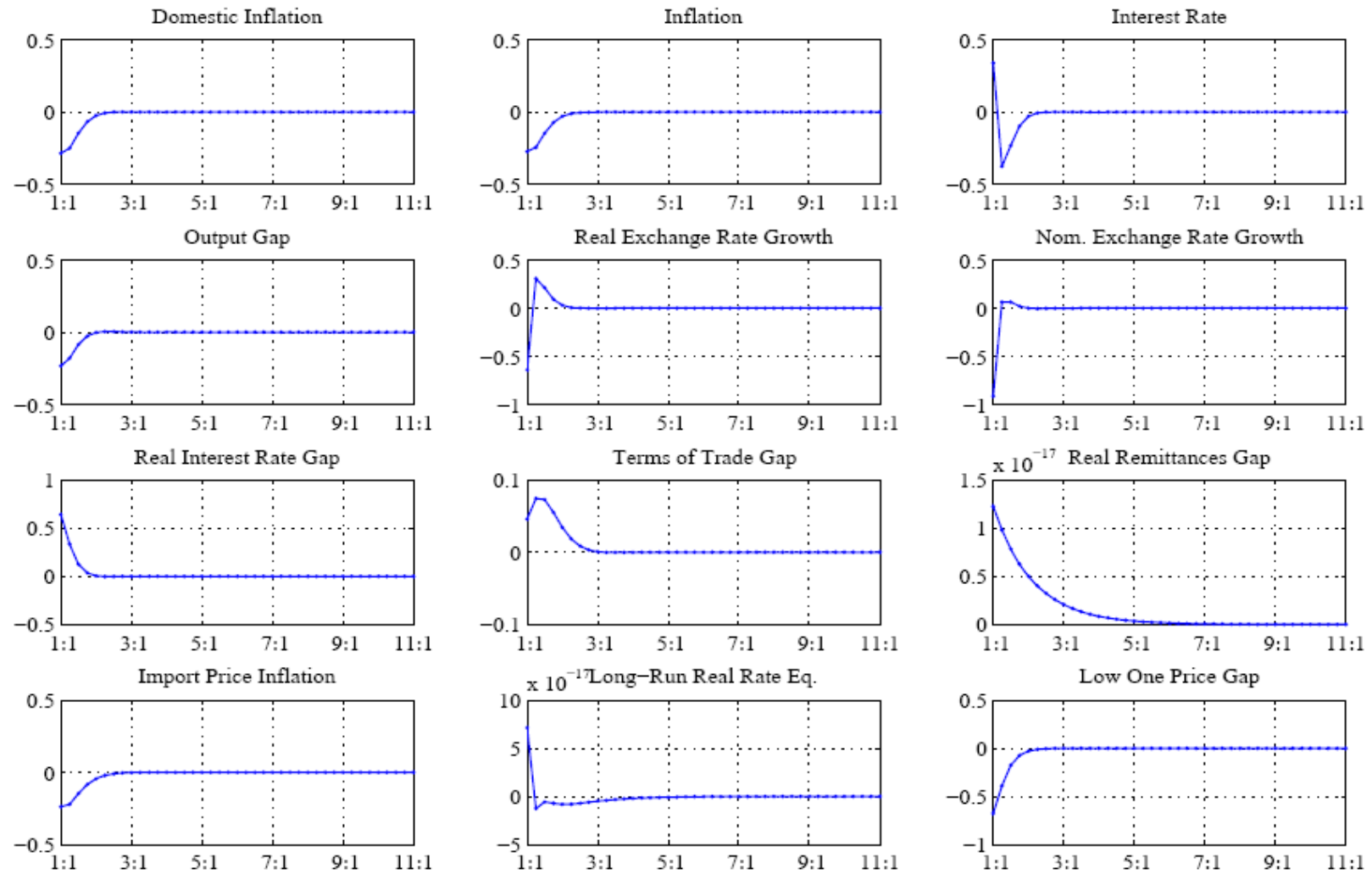
### Price Mark-up Shock



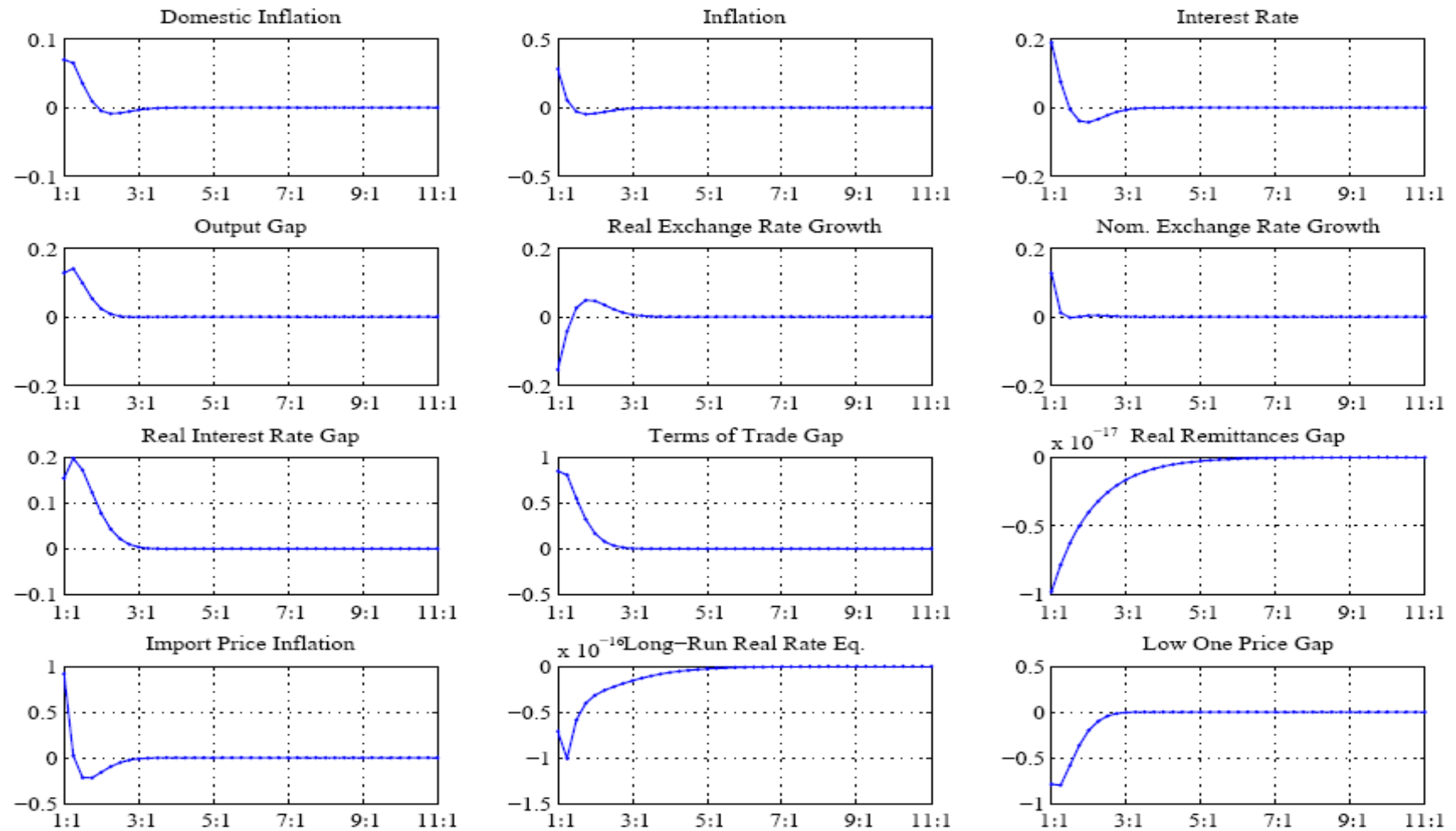
### Demand Shock



### Policy Shock

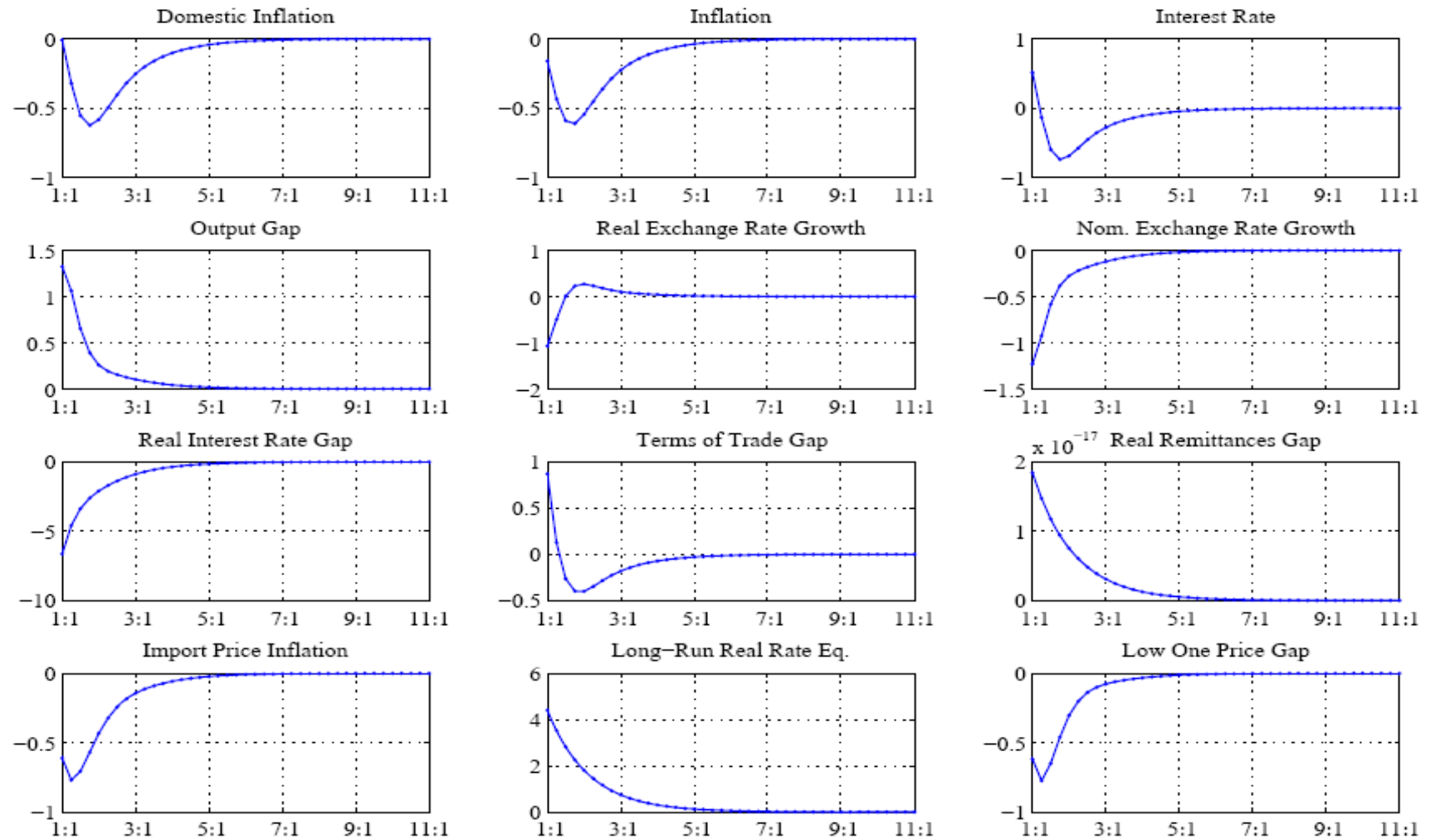


### Import Prices Shock

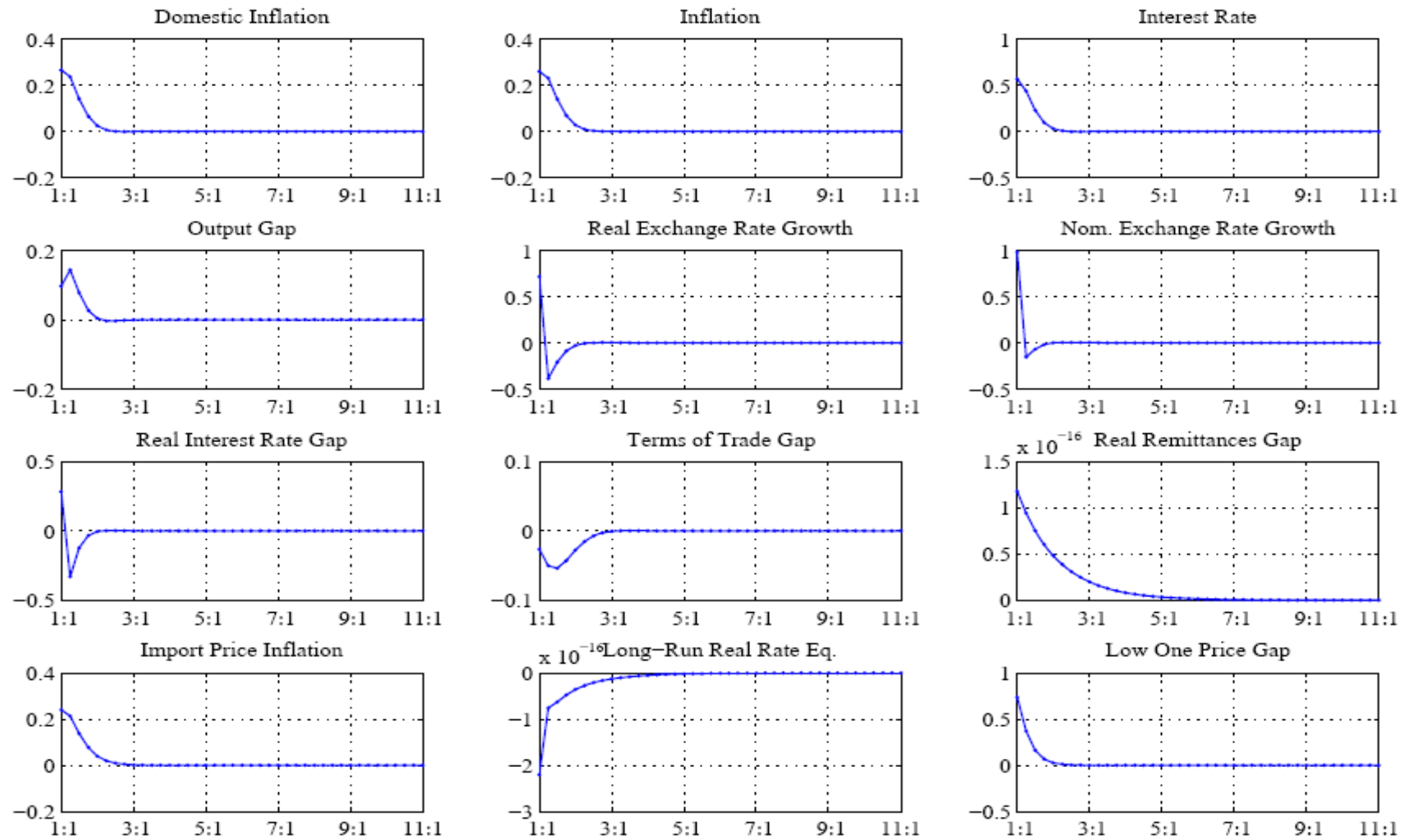




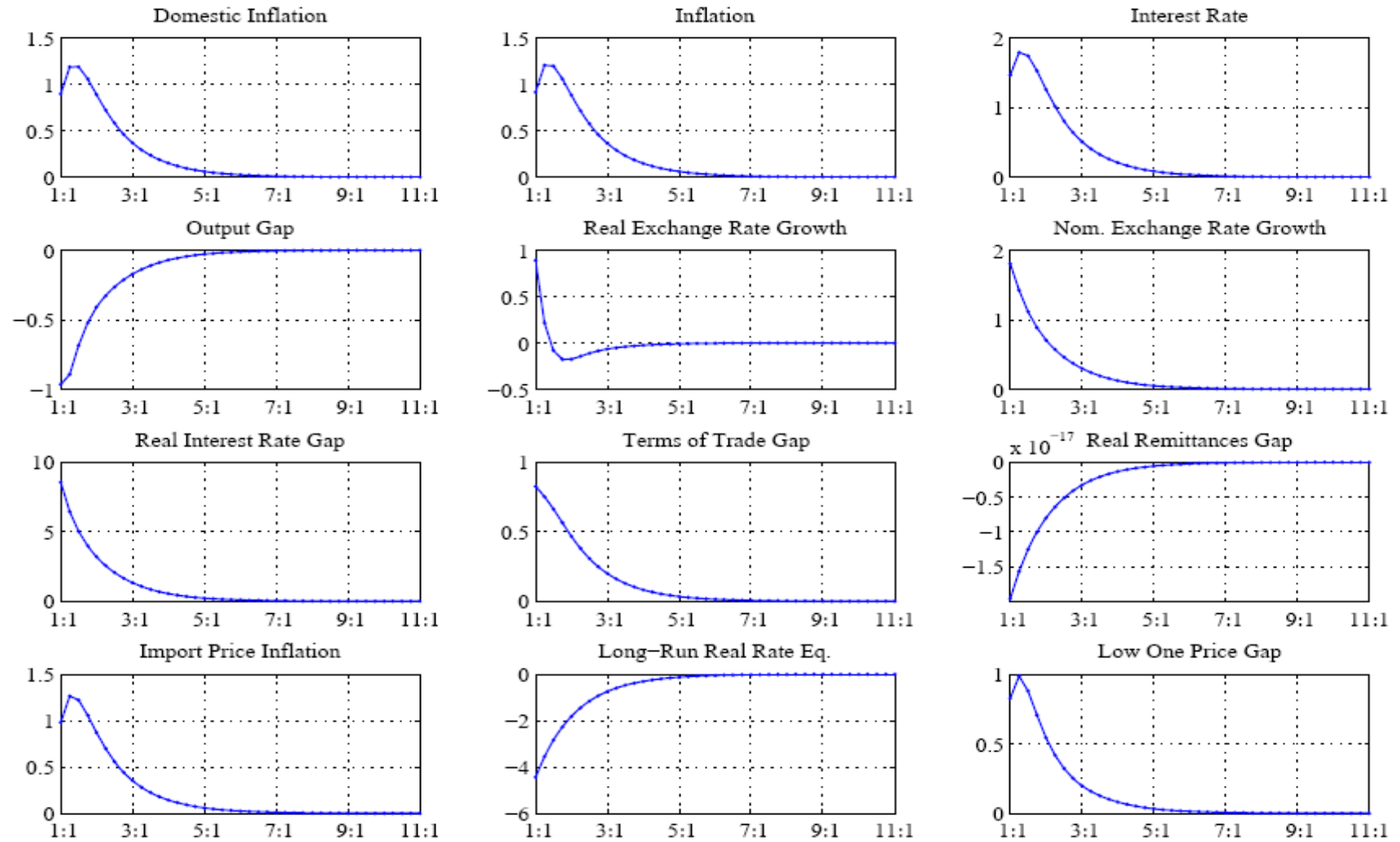
### Foreign Demand Shock



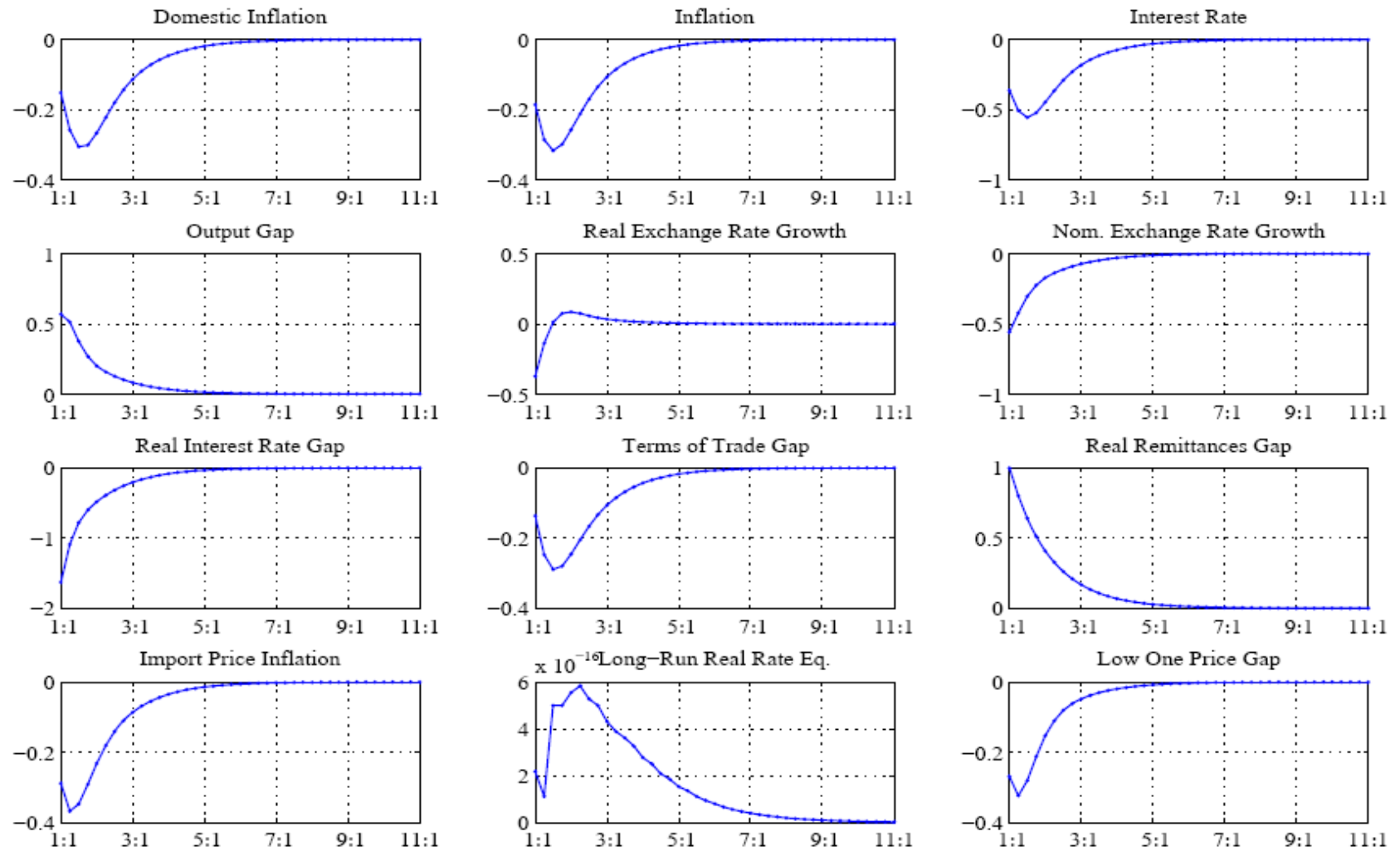
### Real Exchange Rate Shock



### Risk Premium Shock



# Real Remittances Gap



***Appendix E: Model estimated structural shocks with and without remittances***

Figure 10. Estimated Structural Shocks (model without remittances)

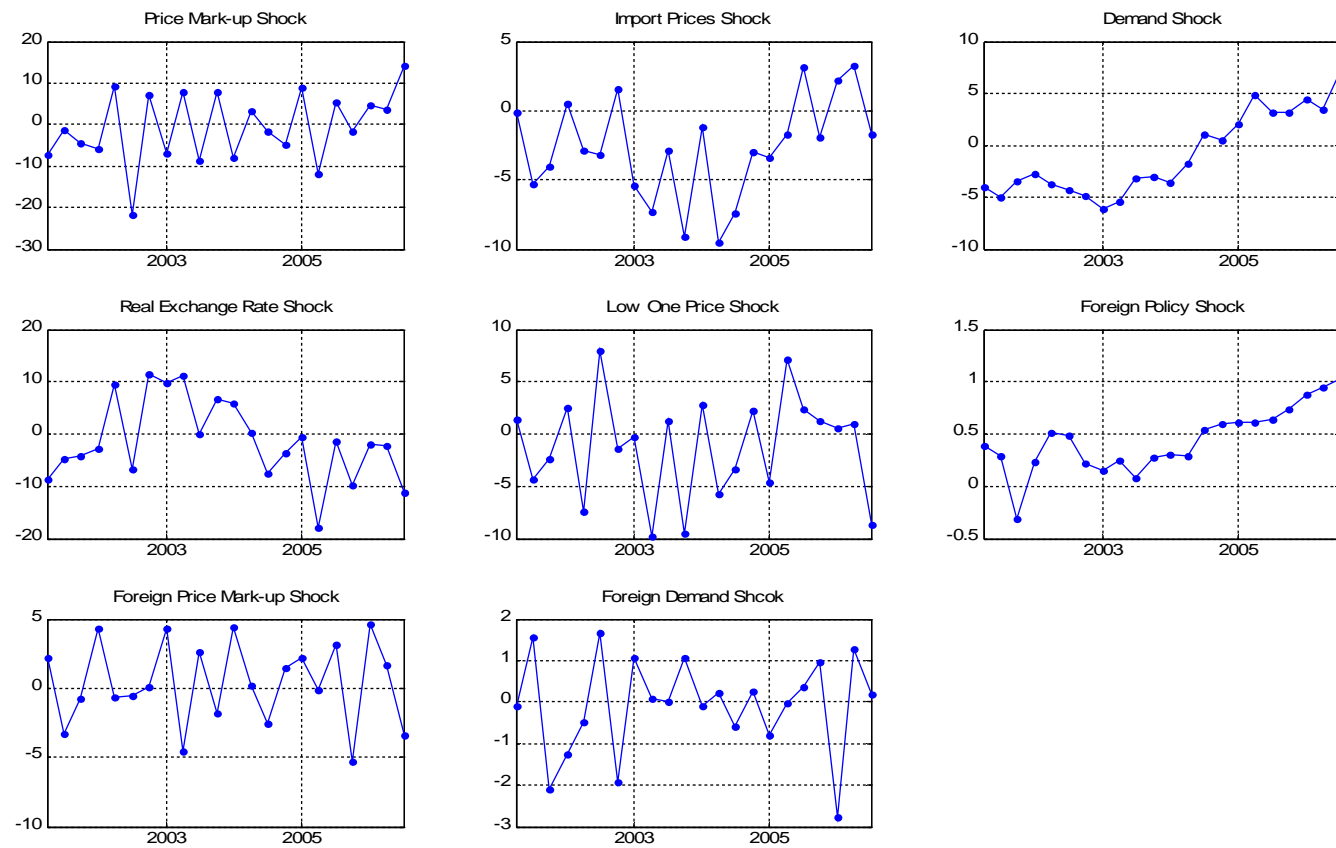
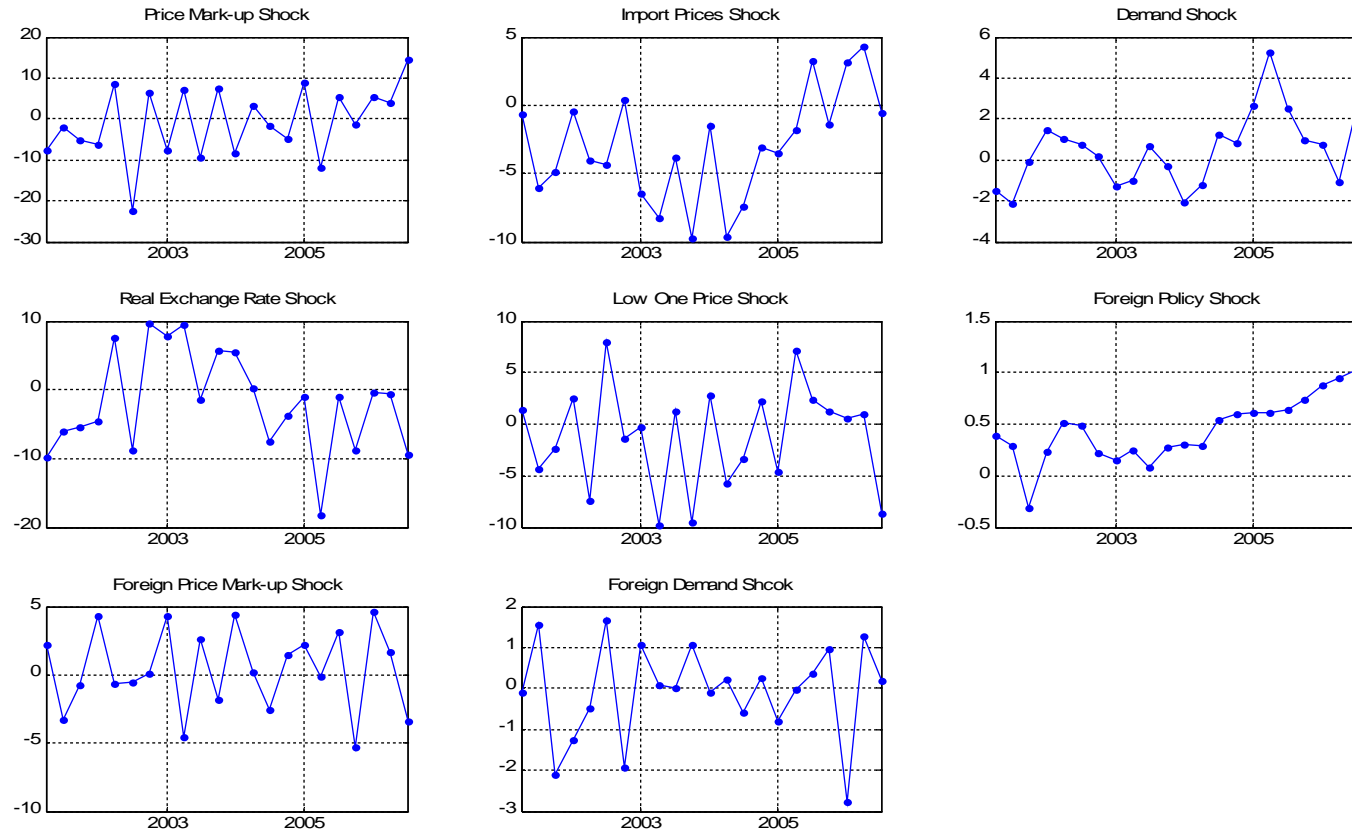


Figure 11. Estimated Structural Shocks (model with remittances)



## ***Appendix F: Impulse responses and tests of VAR analysis***

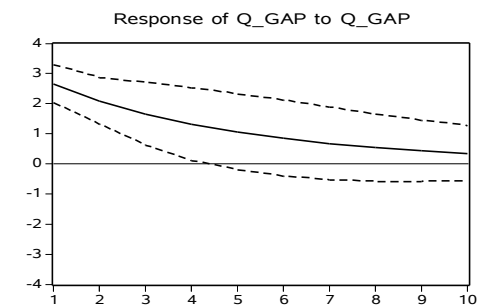
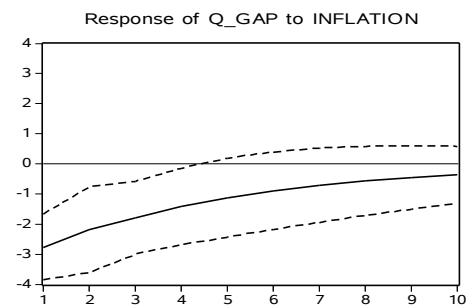
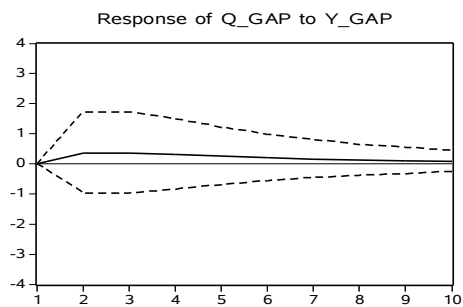
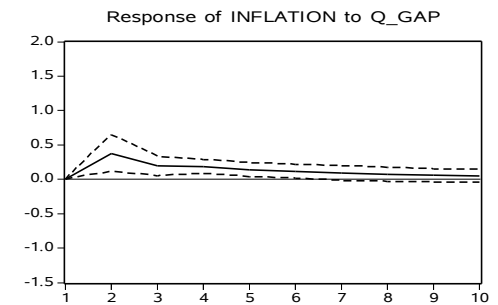
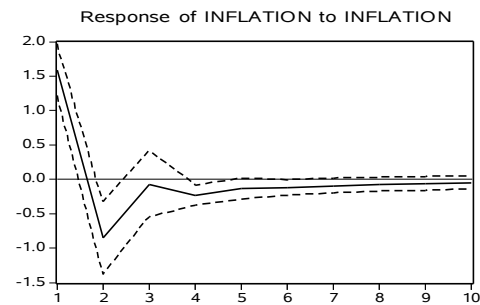
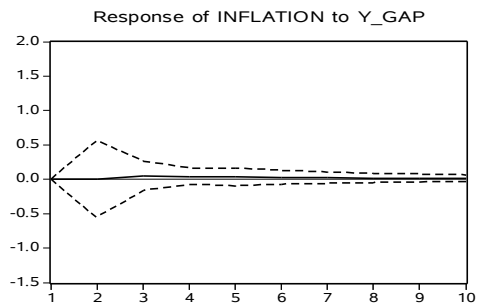
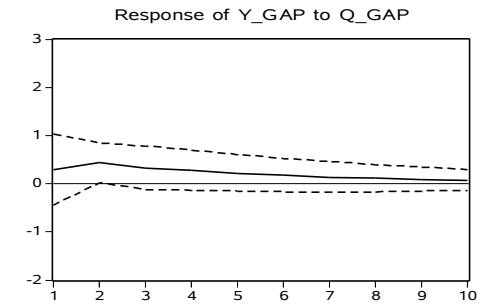
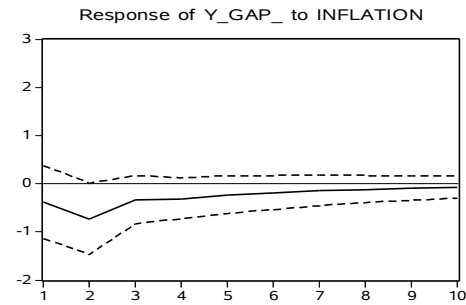
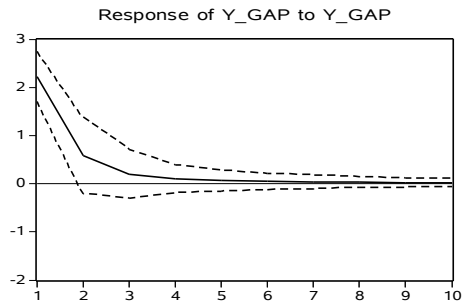


Table 8. The VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-219.8589	NA	568.8981	14.85726	14.99738	14.90208
1	-186.2505	58.25450*	110.8149*	13.21670*	13.77718*	13.39600*
2	-180.8261	8.317437	143.6979	13.45507	14.43591	13.76885
3	-176.8645	5.282077	212.0410	13.79097	15.19217	14.23922
4	-164.8264	13.64322	192.2422	13.58843	15.40998	14.17116
5	-159.1732	5.276292	289.0703	13.81155	16.05346	14.52876
6	-145.8670	9.757911	296.6669	13.52447	16.18674	14.37615
7	-132.4787	7.140412	377.5450	13.23191	16.31455	14.21808

\* indicates lag order selected by the criterion

Table 9. The VAR Residual Normality Tests

Orthogonalization: Cholesky (Lutkepohl)			
Component	Jarque-Bera	df	Prob.
1	1.774876	2	0.4117
2	0.412705	2	0.8135
3	1.267059	2	0.5307
Joint	3.454640	6	0.7500

Table 10. The Roots of Characteristic Polynomial

Root	Modulus
0.797440	0.797440
-0.290318	0.290318
0.236136	0.236136
No root lies outside the unit circle. VAR satisfies the stability condition.	



**Appendix G: The relative performance of interest rate rules**

Table 11: Shocks to Domestic Demand

	Standard Deviations								Loss Function
	Inflation	Domestic Inflation	Imported Inflation	Output Gap	Policy Rate	Nominal Exchange Rate Growth	Real Exchange Rate Growth	Low One Price Gap	$\mu_y = 0.5$ $\mu_s = 0.2$
Strong inflation targeting	0.0006	0.0010	0.0001	0.0322	0.0005	0.0002	0.0008	0.0001	0.6185
Output stabilization	0.0011	0.0011	0.0016	0.0306	0.0010	0.0074	0.0071	0.0071	0.6545
Exchange rate smoothing	0.0007	0.0011	0.0000	0.0324	0.0005	0.0001	0.0005	0.0001	0.6251
Output stabilization with exchange rate smoothing	0.0006	0.0008	0.0008	0.0312	0.0009	0.0031	0.0039	0.0030	0.6188

Table 12: Shocks to Domestic Productivity

	Standard Deviations								Loss Function
	Inflation	Domestic Inflation	Imported Inflation	Output Gap	Policy Rate	Nominal Exchange Rate Growth	Real Exchange Rate Growth	Low One Price Gap	$\mu_y = 0.5$ $\mu_s = 0.2$
Strong inflation targeting	0.00070	0.0013	0.0010	0.0032	0.0018	0.0042	0.0067	0.0042	0.11250
Output stabilization	0.00180	0.0020	0.0031	0.0025	0.0018	0.0110	0.0110	0.0107	0.19520
Exchange rate smoothing	0.00110	0.0019	0.0009	0.0038	0.0018	0.0025	0.0048	0.0024	0.12730
Output stabilization with exchange rate smoothing	0.00120	0.0017	0.0016	0.0033	0.0018	0.0049	0.0067	0.0047	0.14050

Table 13: Shocks to Foreign Demand

	Standard Deviations								Loss Function
	Inflation	Domestic Inflation	Imported Inflation	Output Gap	Policy Rate	Nominal Exchange Rate Growth	Real Exchange Rate Growth	Low One Price Gap	$\mu_y = 0.5$ $\mu_s = 0.2$
Strong inflation targeting	0.0193	0.0180	0.0292	0.0327	0.0142	0.1082	0.0852	0.1012	2.1716
Output stabilization	0.0718	0.0685	0.0860	0.0204	0.0277	0.2834	0.1726	0.2614	5.2999
Exchange rate smoothing	0.0236	0.0231	0.0315	0.0381	0.0165	0.0868	0.0645	0.0777	2.3171
Output stabilization with exchange rate smoothing	0.0350	0.0335	0.0451	0.0325	0.0197	0.1286	0.0868	0.1160	2.9720

Table 14: Shocks to Foreign Exchange Risk Premium

	Standard Deviations								Loss Function
	Inflation	Domestic Inflation	Imported Inflation	Output Gap	Policy Rate	Nominal Exchange Rate Growth	Real Exchange Rate Growth	Low One Price Gap	$\mu_y = 0.5$ $\mu_s = 0.2$
Strong inflation targeting	0.0206	0.0216	0.0179	0.0022	0.0258	0.1247	0.0812	0.1016	1.7161

Output stabilization	0.0350	0.0368	0.0300	0.0056	0.0298	0.1936	0.1215	0.1621	2.8214
Exchange rate smoothing	0.0201	0.0209	0.0179	0.0014	0.0320	0.0941	0.0570	0.0782	1.4801
Output stabilization with exchange rate smoothing	0.0182	0.0189	0.0161	0.0012	0.0297	0.0918	0.0570	0.0757	1.3823

Table 15: Shocks to Remittances

	Standard Deviations								Loss Function
	Inflation	Domestic Inflation	Imported Inflation	Output Gap	Policy Rate	Nominal Exchang e Rate Growth	Real Exchang e Rate Growth	Low One Price Gap	$\mu_y = 0.5$ $\mu_s = 0.2$
Strong inflation targeting	0.0007	0.0006	0.0014	0.0056	0.0032	0.0105	0.0085	0.0089	0.2116
Output stabilization	0.0039	0.0036	0.0047	0.0036	0.0056	0.0237	0.0159	0.0210	0.3913
Exchange rate smoothing	0.0006	0.0005	0.0012	0.0065	0.0038	0.0067	0.0056	0.0058	0.1987
Output stabilization with exchange rate smoothing	0.0018	0.0016	0.0025	0.0055	0.0053	0.0110	0.0078	0.0096	0.2577

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